Editor's Note

Electro-spark machining is a comparatively new technique which has gained prominence with the advent of the new very hard materials currently used for components operating continuously under arduous conditions. The extensive use of these materials has intensified research for new and improved methods of machining which are economically practicable. Spark machining is one of the more promising of these techniques.

Research on this process has been carried out in the U.S.S.R. for some years and "engineered" electro-spark machining units are now widely used in Russian factories. It is probable that the main reason for the current U.S.S.R. interest in electro-spark machining is the severe shortage of strategically important diamond boart in that country.

This book was written as a practical manual for engineers, technicians, foremen and highly qualified workers: in fact for all those concerned with the operation of electro-spark units. The physical basis of working metals by electro-sparking is given in Chapter 1. Information on the physical basis of the method and the main physical laws governing it is provided. Data are also given on the efficiency and accuracy of the method and on the quality of the surface obtained with this technique. The main technological operations and the construction of the simpler machine tools and apparatus are described. A considerable amount of operating experience under factory conditions has already been obtained and the translation includes an outline of the practical experience on electro-sparking acquired in the workshops of industrial co-operative societies.

This book is an abridged translation of the original work. Whilst every effort has been made by the Department to ensure as far as possible the accuracy of this translation, no responsibility can be accepted either for the opinions expressed in the book or for any errors which may subsequently become apparent.

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH
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Introduction

Soviet science and engineering have achieved great success in the development and application to industry of advanced production methods. A good example of this is the electro-sparking method of working metals proposed during the Great Patriotic War by Soviet inventors, Doctor of Technical Sciences B. R. Lazarenki and Engineer N. I. Lazarenko. This is an extremely effective method of working metals. With its aid not only can working to close dimensions of metals be carried out but also a great improvement in the quality of the surface layers can be obtained which is of importance in prolonging the life of expendable parts. The electro-sparking method is particularly effective in working metals or alloys of great hardness. By employing this method it is possible to effect saving in labour and to carry out work without using expensive tools, which are in short supply.

The field of application of the electro-sparking method of working metals is very wide. It is possible with its aid to cut and polish various metals and alloys, cut blind and through holes of various diameters, produce press-tool dies, carry out copying and engraving operations, sharpen tools fitted with cutting edges of hard alloys, effect all sorts of repairs, etc.

Owing to the technological possibilities and high-efficiency of the electro-sparking method it is now widely used in state industries. It is also important to introduce the electro-sparking method on a large scale into workshop practice in industrial co-operative societies engaged in working metals. In Moscow alone there are up to 70 metal working shops in the Mosgorpromsoveta (Moscow City Industrial Soviet) system which every year use tools and various press-tool dies to the value of several million roubles. The application of the electro-sparking method would enable the workshops to lower considerably industrial expenditure and, at the same time, to raise the quality of the finished product.

By employing electro-sparking strengthening it is possible to obtain a considerable increase in the life of tools and quickly expendable machine details used in the workshops of industrial co-operative societies.

Knowledge of the electro-sparking method of working metals, which has now been generally accepted and which has found wide application in industry, is important from the point of view of widening the outlook of engineers and technicians working in industrial co-operative societies and ensuring general technical development and productivity of their work.

A sufficiently detailed knowledge of the electro-sparking method presupposes knowledge of the fundamentals of electrical engineering. Data are given in the book which indicate the possibilities of the electro-sparking method when it is used in operations which are of primary importance to the workshops of industrial co-operative societies.

An attempt is made in the book to generalize the experience of laboratories and industrial enterprises, taking into account the requirements and special

features of the metal working workshops of industrial co-operative soci
Part of the material was taken by the authors from papers already publishe
the subject.

The authors feel it their pleasant duty to express their deep gratitud
Engineers Bystrov, Kuz'minov, Polunin and Chikin for valuable practical a
and for the material which was provided by them.

The authors fully realize that the book is by no means free from defects
they will welcome any critical remarks.

CHAPTER I

Fundamentals of the Electro-spark Method of Working Metals

PHYSICAL BASIS OF THE METHOD

Fundamentally, the electro-sparking method of working metals involves an electric erosion effect. By electric erosion is understood the breakdown of electrode material accompanying any given form of electric discharge. An electric discharge is the passage of an electric current through a gas or a liquid (in some cases a solid) dielectric. A necessary condition for producing a discharge is ionization of the dielectric, i.e. splitting up of its molecules into negatively and positively charged particles. Positively charged particles are known as ions, and those negatively charged as electrons.

If the ionization of a gas is produced by external factors (effect of dissimilar emissions or radiations or high temperatures, presence of charged particles of dust, etc.), and their removal causes a cessation of discharge, this latter is known as a conditional (dependent) discharge. If, however, the discharge, due to certain factors, supports ionization of the material, whilst eliminating these factors itself (by its own powers) and through processes accompanying the discharge, then it is called unconditional (independent). Conditional and unconditional discharges, according to their type, may be stationary and non-stationary.

When the electrical, thermal, and other characteristics of the discharge during its passage remain unchanged, the discharge is stationary; if, on the other hand, these characteristics change with time the discharge is non-stationary. A special variant of the non-stationary type is an impulse discharge with a duration of 10^{-4} to 10^{-8} sec. Such discharges, known as "sparking", are used in metal-working technique. In the practical electro-sparking method of working the discharges are usually produced—with close contiguity of electrodes (anode and cathode)—by a general arrangement that ensures the required form of discharge. In such cases, the electrodes are disposed either in an air or a liquid dielectric medium, depending on the type of operation to be undertaken.

Let us look at the first case: discharge in a gaseous medium. During the drawing together of the electrodes, at some pre-determined distance between them, the potential intensity of the electrical field increases so much that individual electrons begin to break loose from the surface of the cathode and are impelled towards the anode under the influence of the field forces. In their movement in the inter-electrode space the electrons will collide with neutral molecules of gas and will ionize these. At some time or other the ionization of the interspace between the electrodes becomes such that a narrow channel of continuous conductivity is formed. At that moment there is a considerable flow (avalanche) of electrons along the channel thus formed, towards the anode, constituting by such movement a momentary current impulse, or discharge.

There is an alternative conception of discharge in this case, in which there is contact initiation of discharge, when the current impulse is produced at the moment of contact of individual micro-peaks or projections on the surface of the electrodes. The liberation of energy accompanying the discharge leads to the production of extremely high temperatures causing fusion and partial vapourization of the metal at the point of discharge action. The metal in the form of liquid drops is then dispersed into the space surrounding the electrodes by the surge of explosive gaseous waves produced during discharge.

Thus each discharge creates its own heat impulse, causing breakdown of electrode material. Moreover these momentary heat impulses in periodical sequence produce deep physico-chemical transformations in the surface layer of the electrode material. The transfer of elements of material of the interacting electrodes and diffusion of elements of the surrounding medium are also facilitated by this transformation of the surface layer.

Sparking in a liquid dielectric proceeds somewhat differently from that described for a gaseous medium. Under actual conditions most electro-sparking operations are conducted with electrodes immersed in a liquid dielectric (mineral oils, kerosene) contaminated with various conductive substances. Moreover the particles removed from the electrodes by the spark discharge fall into the liquid medium, are cooled, and contaminate the space around the electrodes with colloidal suspensions of metal. These suspensions and also the products of decomposition of the liquid dielectric, drawn into the inter-electrode space under the action of the field during the preliminary phases of the discharge, are distributed along the electric lines of force, forming unique current conducting "bridges". Very rapid heating and therefore breakdown of one such bridge causes local gas formation in the liquid, ionization of a certain quantity of molecules, and consequently the discharge.

Discharge in a liquid brings about the same effects as in a gas, i.e. momentary fusion and vapourization of electrode material, whereby the gas formed as a result of decomposition of the working liquid forces the molten metal into the liquid around the electrodes. Comparing the effects accompanying discharge in liquid and gaseous media it is necessary to note that the spark discharge in liquids leads to a more intense ejection of anode particles into the surrounding space, and in a gaseous medium to a partial transfer and diffusion of the torn-off anode particles into the surface of the cathode.

Both these phenomena are utilized in the electro-sparking method of metal-working: the first in performing dimensional working operations (drilling holes, preparing stamps and dies, cutting tools, etc.); and the second in operations connected with the strengthening or "toughening" of a tool and building up of surfaces.

GENERAL PRINCIPLES FOR USE IN THE WORKING PROCESS

To achieve the electric spark process in practice it is necessary to provide an electric circuit in which the component to be worked and the working tool are the electrodes between which periodic impulse discharges occur. In general, for electro-sparking machines working at 36 to 220 volts, the impulse discharge is obtained through discharge of condensers arranged in parallel to the electrodes and periodically charged from a direct current supply. Such an arrangement comprises two independent circuits: the charging circuit, with current source, charging resistance, condensers; and the discharging circuit, comprising a bank of condensers and the electrodes. In this arrangement the bank of condensers acts as a secondary source of energy, used in the process of discharge for a very short period of time which is governed by the impulse current breaking down the electrode metal.

In order that the duration of the discharge shall not exceed a specified value—beyond which the impulse ("spark") discharge changes into a stationary arc discharge unsuitable for the working operations—the value of the working current for a given capacity is limited by means of a charging resistance. The following relations between capacities and currents have been established practically to ensure an impulse discharge.

TABLE 1

No.	1	2	3	4	5	6	7	8	9	10
Capacity (mfd) ..	2	4	6	10	30	50	100	200	300	500
Current (amp) ..	0·16	0·32	0·4	0·8	2·4	4	8	16	24	40

While the discharge circuit is working the distance (clearance) between the electrodes is gradually increased, depending on the extent to which the electrode metal is broken down. After a certain time this clearance between the electrodes has become so large that the applied voltage is insufficient to produce the discharge, and removal of metal ceases. Continuity in the process of working can only be maintained when the required clearance between the electrodes is maintained automatically. If the rate of electrode feed is decided arbitrarily this leads either to complete contacting of the electrodes or to an increase of clearance beyond the permitted maximum. In both cases removal of metal ceases. The mean value of the current in the discharge circuit, under given voltages and resistances in the charging circuit, is determined by the extent of clearance between electrodes. In practice, when the electrodes are closed the clearance is nil, and the current in the charging circuit—in the given case a short-circuited current—is determined by the relation: $I_{sh\,c} = \frac{U}{R_{ch}}$ where $I_{sh\,c}$ is short-circuited current[1], U is applied voltage, and R_{ch} is resistance in the charging circuit.

If the clearance is greater than the maximum permitted then the charging current will be nil. A certain definite value of charging current is associated with a particular value of the clearance between the limits of zero and maximum. Changes in strength of the charging current related to these changes in clearance are used in electro-sparking machines for ensuring automatic feed of electrode tool. It is easy to construct such a control which, responsive to changes in charging current, depending on clearance, would automatically alter the position of one of the electrodes, thus regulating the rate of feed.

The automatic feed of the electrode is one of the basic features of an electro-sparking machine, determining the technical characteristics of the process and the reliability and convenient operation of the machine. All the existing types of automatic control may be fundamentally divided into two groups—electromagnetic and power—according to their design features.[2]

[1] By this term must be understood maximum strength of charging current at the moment when potential of condenser is nil.

[2] A more detailed account of the construction of different types of controls is given in corresponding sections of Chap. II.

In Fig. 1 is shown the general arrangement of a machine with electro-magnetic solenoid control. As shown earlier, A I D B is a typical circuit for electro-spark working; and G E F H is the electro-magnetic control circuit. The latter includes a solenoid with core, resistance R controlling current in solenoid, and part of the charging resistance R_{ch}. The lower part of the solenoid core serves as spindle for taking the working electrode. To facilitate operation of the solenoid the weight of spindle and electrode is partly equalized by a balancing weight.

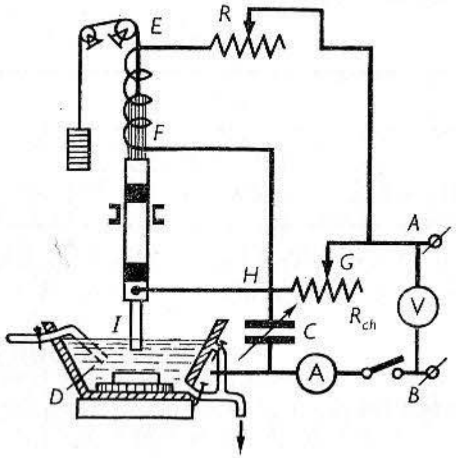

Fig. 1. General arrangement of electro-spark circuit with automatic (solenoid) electrode feed control

R—resistance controlling current in solenoid; R_{ch}—charging resistance; C—condenser unit; V—voltmeter; A—ammeter.

The control works as follows: with open (disconnected) electrodes, when the clearance exceeds the maximum permitted limit, there is no drop in potential at the charging resistance, and windings of the solenoid are not energized. Under this condition the core of the solenoid is moved downward due to its own weight until current flows in the charging circuit, with potential on the charging resistance and current in the solenoid windings. The magnetic field formed within the solenoid creates a force tending to draw up the core. This force, together with the pull of the compensating weight both acting in the same direction, will raise the spindle until the necessary clearance is established at which discharge can take place, and the system will be maintained in equilibrium.

The current in the charging circuit weakens in proportion to the erosive disintegration of electrode material and the resulting increase in clearance between them, causing a corresponding weakening of current in the solenoid windings. As a result the lifting power of the solenoid is reduced, equilibrium disturbed, and the spindle lowered to the extent of the initial clearance. With a reduced clearance, e.g. with exceptional accumulation in the inter-electrode space of dispersed particles of metal, the increase in the charging current and in the solenoid current increases its lifting power, and the spindle now raised restores the required clearance. In order to adjust the electrodes to the necessary (optimum) spacing, and for accurate control of the equalizing forces electromagnetic com-

pensation is used in conjunction with compensatory loading of the spindle. In this case coils or turns of the compensatory windings fed from an independent current source are arranged on one holder with the primary windings of the solenoid.

FACTORS GOVERNING THE PROCESS OF ELECTRO-SPARK WORKING

The technological characteristics of electro-spark working are: high efficiency, good finish of the worked surface, and accuracy. The basic factors governing these characteristics include:

(1) parameters of the electrical circuit,
(2) precision of adjustment of feed control,
(3) electrode material,
(4) nature of the working liquid.

In the electro-sparking method accuracy of working depends to a considerable extent on the kind of work to be done and the design of the electrode tool. Therefore for convenience the effect of these factors governing accuracy of working will be dealt with in Chapter II—"Technology of Electro-spark Working".

Parameters of the electrical circuit. The charging current I and the capacity value C, are the most essential factors in determining the technological characteristics of electro-spark working.[1] The efficiency of this method, in terms of the amount of disintegrated metal removed from the component in unit time, depends primarily on the amount of energy developed in the erosion zone and the discharge frequency. The energy of a single discharge, neglecting losses in the condensers and leads of the discharge circuit, may be given as: $W_d=\frac{CU^2}{2}$

where C is capacity of condenser in farads,

U is potential on condenser at moment of discharge, in volts,

W_d is energy of discharge in joules.

The frequency of discharge is inversely proportional to the time of build up of potential in the consenser to that of spark-over, i.e. $N=\frac{1}{t_i}$ where N is discharge frequency and t_i time of potential increase. The time of increase in potential (t_i) may be taken conditionally as equal to the time of fully charging, given as follows: $t_{ch}=4{\cdot}6\frac{CU}{I_{sh\,c}}$ where C and U are the same parameters (measured in the same units) as in the previous formula, and $I_{sh\,c}$ is the strength of the short-circuited current[2]. In view of these expressions it is possible to formulate the expression for frequency as $N=\frac{I_{sh\,c}}{4{\cdot}6CU}$.

Fig. 2 shows the relation between changes in efficiency (time in minutes) and values of capacity (in mfd) in broaching holes of 8 mm diameter in steel RF-1, with a copper-graphite electrode, using 220 v. From the curves it is evident that

[1] Since, in most electro-sparking machines, the control system of working is usually based on changes in value of the charging current and of capacity—with constant voltage—the question of the effect of this latter on the technological characteristics has been purposely omitted here. The subject is dealt with in the appropriate sections of Chap. II.

[2] Actually, as will be mentioned later, sparking over in the erosion space may occur up to the point of complete discharge of the condenser.

increase in efficiency is considerably less in the capacity range of 150-200 mfd; and with further increase in capacity there is almost no increase in efficiency. This latter is explained by the fact that, besides the increase in energy of the discharges, the corresponding reduction in their frequency leads to a constant value for the power transmitted to the erosion space. Therefore an increase in capacity above 300 mfd at the electrode must be regarded as inexpedient, as this adds little to efficiency.

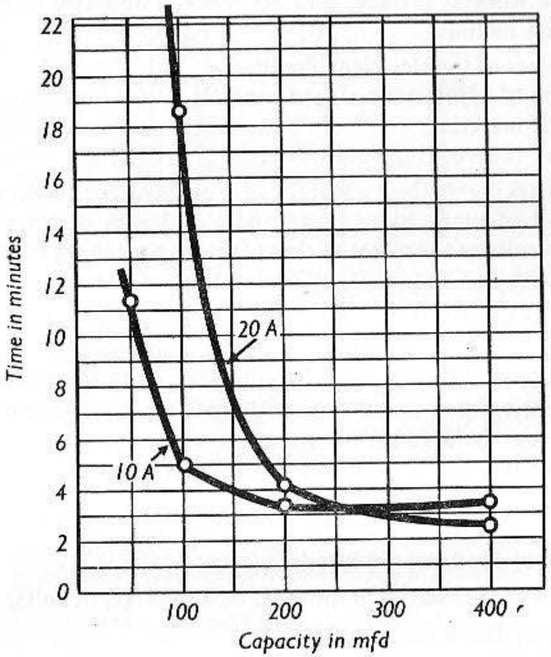

Fig. 2. Relation between changes in duration or time and value of capacity

For increasing the efficiency of working at constant capacity it is necessary to increase the charging current, for this, without changing the energy of individual discharges, raises their frequency. But the charging current can only be increased up to a certain point. In Fig. 3 is shown the relation between efficiency and strength of charging current in working steel RF-1 at 220 v. From the curves it is seen that, for a given voltage, as the charging current is increased, efficiency at first increases rapidly, then slows up somewhat; and with further increase efficiency falls. This fall may be explained as follows. With increased frequency of discharge there is correspondingly more power delivered to the erosion zone, causing such intensive gas formation that the working liquid periodically escapes from the working zone, and the stability of the process is disturbed, resulting in reduced efficiency.

Practical experience shows that with capacities from 2 to 300 mfd the optimum strength of charging currents, to ensure stability, is in the range of 0·32 to 24 amp.[1]

[1] Depending on the extent of gasification the limiting values of charging current mentioned by us and in many literature references indicate the restricted range of working conditions to ensure stability in the process.

Each discharge leaves on the surface of the workpiece a trace or mark in the form of an indent (lune) of irregular form and from 0·03 to 0·3 of its diameter in depth. As has been already established earlier the energy of discharges rises with increasing capacity at constant voltage, and accordingly increases the depth and diameter of the lunes which eventually leads to a poorer surface finish. The strength of the charging current shows much less effect on surface finish. This is explained by the fact that, with variation of charging current, only the degree of overlapping of the lunes is changed and not the energy of an individual discharge. A five- or six-fold increase in the charging current does not lower the surface finish by more than about one class.[1]

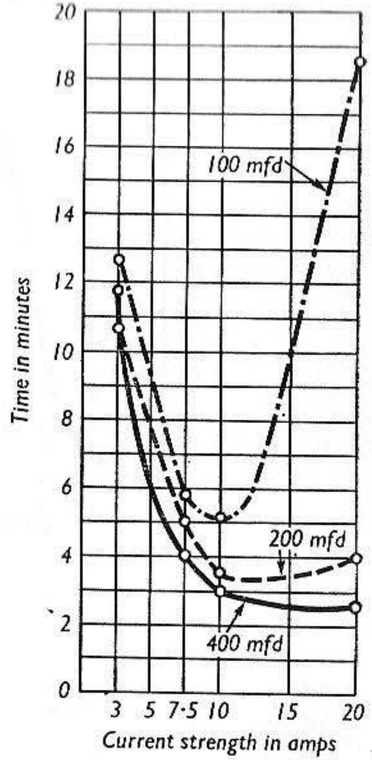

Fig. 3. Relation between working efficiency (output) and strength of charging current

Adjustment of the feed control, when operating the electric spark method, is actually reflected both in efficiency of working and in the surface finish. The build up of potential in the condenser follows an exponential law: first proceeding rapidly and then markedly slowing down. During the first half of the charging period the condenser voltage reaches 0·9 of that of the supply source; and during the second half the condenser is only recharged for 0·09. If the spacing established between the electrodes is such that the condenser could be discharged at a voltage equal to 0·85 to 0·9 of that of the supply then the number of discharges could be considerably increased. In this case, despite the reduced energy of each single discharge (cf. Table 2) the momentary removal of metal is increased. For given values of the electrical parameters of the charging current the efficiency of the process will vary in relation to variation of the gap; and maximum efficiency will correspond to the optimum gap (Fig 4) which is considerably less than its maximum value.

Reduction in the energy of discharge using partially charged condensers leads to a decrease in the dimensions of the individual lunes (cf. Table 2), and therefore to better surface finish. If the clearance is greater than its optimum value the surface finish is worse, with greater energy of discharge, and conversely, with a less than optimum clearance, surface finish will be improved. Therefore the system adopted should be adjusted so that the inter-electrode gap is less than or

[1] *Translator's note:* There are fourteen classes of surface finish in Russian standard—GOST 2789–45. See Appendix II (b).

equal to the optimum as determined from conditions governing the best technological values for working.[1]

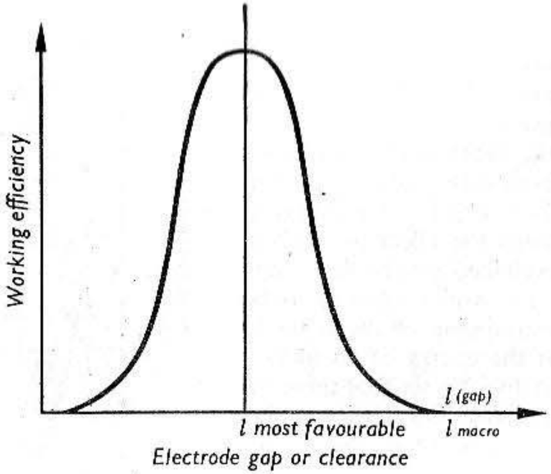

Fig. 4. Relation between working efficiency and size of gap between electrodes

TABLE 2

Time from start of charging as % of full charge	Charging voltage as % of feed voltage	Energy of charging as % of total energy	Diam. of lune as % of max. possible
55	92	91	92
50	90	80	90
45	87	—	87
40	85	72	85
35	80	—	80
30	75	56	75
20	60	36	60
10	37	14	37
5	20	—	20

Material of electrodes (component and tool) in electro-spark working predetermines to a considerable extent the maximum efficiency and surface finish attainable. Since thermal processes are the basis of erosive disintegration of the electrodes, the efficiency and surface finish in such cases will be governed largely by the thermal properties of the component and tool material. Hardness and other mechanical properties of the worked material have little effect on efficiency of working. For example, hardened tempered steel is worked better than untreated steel, and duralumin better than copper.

The more effective disintegration of anode component material in a spark discharge depends to a large extent on the quantitative distribution between the electrodes of the energy delivered at the moment of discharge into the erosion zone. This quantitative distribution of energy, for the same anode component material, is determined by the properties of the cathode-tool material. Varying the tool material may alter considerably the allocation of energy at the disintegrating anode, and therefore efficiency of working.

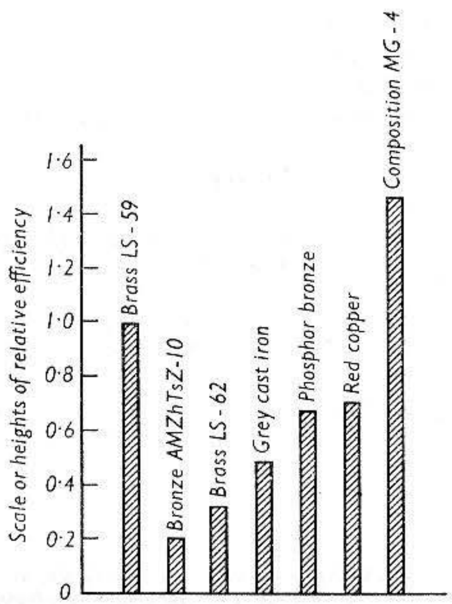

Fig. 5. Relative workability of steel U8A with different tool materials

In Fig 5 is shown the comparative machinability of steel U8A with tool electrodes of different materials. The efficiency of working this steel with a brass electrode mark LS59 has been taken as unity. The diagram shows that changing the material of the tool may vary the workability sevenfold. Since a discharge with the same energy removes from different metals different volumes of material under the same conditions of working the surface finish with different metals will also vary. Thus, all other conditions being equal, metals which are more efficiently worked by the electro-sparking method have a worse surface finish than those of which the working proceeds less intensively.

Changing the material of the tool whilst that of the component is unchanged affects the efficiency of the method and involves changes in the finish of the worked surface. If, in working steel U8A with a tool of brass LS59, the surface finish is of the fifth class of Russian standard GOST 2789-45, with $H_{mean} = 6$ microns, then, working under the same conditions with a copper-graphite electrode, efficiency is higher; but the surface finish of the component is somewhat worse, with an H_{mean}, for example, of 8·1 microns.[1]

Nature of the working fluid. All known electro-spark operations, except toughening or strengthening, are done in a liquid medium which prevents

[1] Correct adjustment to the optimum gap is indicated by uniformity of discharges produced blending together in continuous sound, and the steady readings of voltmeter and ammeter. In such a case, as a rule, strength of working current is 0·6–0·7 of that of the short circuit.

[1] *Translator's note:* The Russian H_{sk} is taken to be H_{mean}, as compared with H_{max} for the highest "peaks"; GOST 2789–45 is not the latest edition of this standard; but no doubt the classes remain much the same.

adhesion of the disintegrated particles to the working surface of the tool, and intensifies the process of electric erosion. Practical experience has shown that the most suitable materials for this purpose are organic liquids, such as kerosene, transformer or spindle oil, and, in some cases, water.

The figures given in Table 3 show that efficiency of working which is fairly uniform for the first three liquids is considerably less when using water. Decrease in efficiency of working when using water is explained by its high electrical conductivity causing incomplete charging up of the condensers, and also partial dissipation of energy on processes not connected with removal of metal (electrolysis).

TABLE 3

Working fluid	U is 270 v, C is 250 mfd, $I_{sh\ c}$ is 27 amp		U is 270 v, C is 94 mfd, $I_{sh\ c}$ is 13 amp	
	Efficiency in mm³/min	Depth of broaching in min	Efficiency in mm³/min	Depth of broaching in mm
Kerosene	148	4·8	67	9·3
Transformer oil	168	4·8	66	9·4
Spindle oil No. 2	171	4·8	66	9·5
Water	76	2·7	17	4·6

NOTE: Component material is steel U8A, tool material is brass LS59 (from data of OKB MM. —Special Design Office of Ministry of Materials).

From Table 3 it is evident that differences in efficiency when using the organic liquids mentioned as dielectrics are very slight, and therefore still less divergence will be observed in the finish of the worked surface. The use of kerosene involves a fire risk, so that as a rule the mixture used comprises 50 per cent kerosene and 50 per cent transformer or spindle oil.

CHAPTER II

Technology of Electro-spark Working

FUNDAMENTALS

In carrying out any technological operation it is necessary to maintain a definite accuracy of working and surface finish as prescribed or determined by the technical conditions. In electro-spark working the surface finish and dimensional accuracy of the workpiece depend in large measure on the electrical conditions selected. Three grades of surface finish may be distinguished: rough (or coarse), medium (or semi-finishing), and fine (finishing). A faster rate of working is possible with the coarse regime than with the medium or fine. For example in Table 4 characteristic values of the three kinds of regime are shown, and in Table 5 the maximum outputs attainable by each group in broaching steel with an electrode tool of brass LS59 are given. It is clear from Table 4 that there are no sharp lines of demarcation between the groups, and such division is to a certain extent arbitrary. In most industrial plants the voltage of the charging circuit is constant at 220 or 120, and the working regime is controlled by varying the values of capacity and charging resistance.

TABLE 4. *Type of Regime*

COARSE			MEDIUM			FINE		
Potential in v	Charging current in amp	Capacity in mfd	Potential in v	Charging current in amp	Capacity mfd	Potential in v	Charging current in amp	Capacity mfd
150–200	15–30	150–500	100–150	5–15	30–150	30–90	0·2–1	0·25–15
—	—	—	100	30	600	100	5	10
—	—	—	100	15	200	100	0·25	2
220	40	500	220	8	100	220	0·4	6
220	24	300	220	4	50	220	0·32	4
220	16	200	220	2·4	30	220	0·16	2
—	—	—	220	0·8	10	—	—	—
100–150	10–30	400	40–100	2–10	40	20–40	0·1–2	4
200–250	12–50	300–2000	100–200	5–12	100–300	50–100	3·5	30–100

TABLE 5

Regime	Efficiency in mm³/min
Coarse	150–330
Medium	20–150
Fine	up to 20

Quality of surface. When machines break down the defect often begins in the surface layers of their component parts. The mechanical properties of these surface layers depends to a considerable degree on the kind of working or processing applied in the final operation on the component. Under surface quality are included both the geometrical (micro- and macro-) and the physical (micro-hardness, micro-structures, etc.) properties of the surface, determining the wear resistance, the corrosion resistance, and the fatigue limits of the component. The physical quality of a surface is determined by the divergence of the physical properties (micro-hardness, micro-structure, etc.) of the surface layer of metal from the physical properties of the metal in the bulk of the component. The geometrical quality of the surface is determined by the deviation of the actual surface from the conventional standard—an ideally smooth surface. In this case macro-geometry (non-flatness, curvature, ellipsity, conicity, etc.) involves deviations of small height and very large pitch; and micro-geometry (micro-irregularities) deviations of about the same height but of much smaller pitch or extent.

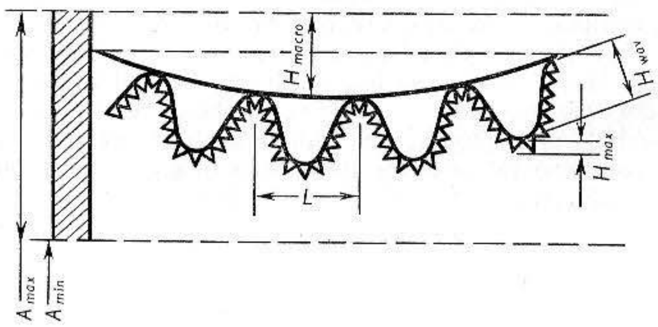

Fig. 6. Types of deviation surface form from nominal

If macro-divergences having uniform repetition or sequence and of similar dimensions are observed on the surface then they are of the so-called wavy type. Determination of the type of observed deviations is made from the value of the ratio $\frac{L}{H}$ (pitch: height of unevenness, Fig. 6)—

for macro-deviation $\frac{L}{H_{macro}}$ exceeds 1000

for waviness $\frac{L}{H_{wav}}$ ranges from 50 to 100

for micro-deviations $\frac{L}{H_{max}}$ is from 10 to 50.

The specific nature of the removal of metal in electro-spark working essentially distinguishes the micro-geometry of surfaces worked by this method from that of a surface mechanically machined. Each discharge, removing particles of metal from the surface of the component, produces thereon depressions in the form of lunes approximately spherical in shape, and no more than 0·3 of diameter in depth. After a series of discharges, i.e. after working, the surface is found to be covered with numerous lunes overlapping one another. Under the action of a discharge the worked metal surface is atomized, irregularities and excrescences are formed that also distort their outline.

The finish of a surface worked by electro-sparking is determined by the geometrical dimensions of the lunes, the extent of their mutual overlapping, and also the size of the excrescences formed. Table 6 gives values of surface finishes obtained in working steel U8 under different regimes.

TABLE 6

Regime	Material		Class of finish as per standard GOST 2789–45
	Anode	Cathode	
Coarse	Steel U8	Brass LS59	3–4
Medium	Steel U8	Brass LS59	4–5
Fine	Steel U8	Brass LS59	5–6
Fine	Steel U8	Graphite EG-2	6–7

From Table 6 it will be seen that it is possible to attain a surface finish corresponding to Class 7 of GOST 2789-45. To obtain still better surface finish it is necessary to lower the voltage of the source supply, since, with reduced potential, the height of the irregularities is markedly lessened. However, voltage control is not feasible in all cases, and, in addition, lowering the efficiency of the regimes to achieve surface finishes above Class 7 in GOST 2789-45, considerably increases the working time and makes the process less attractive economically.

In those cases where a surface finish better than normal (Class 8 and higher) is required it is usual to combine electro-spark working with mechanical finishing. It is necessary to point out that surfaces worked by the electro-spark method have a matt appearance, even with a very high degree of finish.

For determining the finish of surfaces worked by the electro-spark process, methods and apparatus are used whereby the size of irregularities can be evaluated after mechanical working. The size of irregularities in working with the coarse and medium regimes is determined with the aid of a double Linnik microscope. For measuring surface irregularities in working with fine regimes various profilometers are suitable and, for very high finishes, a micro-interferometer can be used. It is not advisable to measure the roughness of a surface that has been worked under the coarse and medium regimes with a profilometer, as this may result in chipping or fracture of the diamond-tipped stylus. In Table 7 the limits of surface finish range attainable in various operations with the electro-spark process are shown.

TABLE 7

Type of working	Class of finish as per GOST 2789–45									
	1	2	3	4	5	6	7	8	9	10
1. Electro-spark broaching: coarse	------	------								
medium		------	------	------						
fine			------	------	------	------	------			
2. Cutting	------	------	------	------						
3. Grinding			------	------	------	------	------	------	------	------

During electro-spark working the surface layer of metal undergoes deep structural changes. The heat developed under discharge partly melts and vapourizes a certain amount of metal. The subsequent momentary drop in temperature of the molten metal from a few thousand degrees to its normal value causes a marked hardening of the surface layer in the zone of discharge activity. Moreover, the pyrolysis gases formed, at the moment of discharge, by decomposition of the working fluids (kerosene, oil), diffuse at the high temperature into the surface layer. As a result of the changes described, a whitish layer is formed on the surface of steels with a high degree of hardness, wear resistance, and relatively good anti-corrosion properties. In addition, it has been found that the fatigue strength of a component is appreciably lowered where this white layer has formed. The nature of the change in micro-hardness of the surface layer indicates that a tempering process occurs in mild steel, and secondary tempering and annealing processes in hardened steels.

The white layer formed on their surface in the working of tempered steels constitutes an austensite-martensite secondary transformation (or hardening) with a hardness exceeding that of the base or underlying metal. With an untempered steel the hardness of the white layer attained through tempering during the process of electro-spark working is somewhat lower than that of steel normally hardened. This is explained by the fact that, at the high speed of the thermo-electric process, exposure to a temperature above the critical is clearly insufficient to complete the structural change.

The thickness of the white layer, depending on the operating regime and composed of worked material and working fluid, ranges from 0.01 to 0.04 mm. Below the top hardened white layer is an annealed layer varying in thickness from a few hundredths of a mm to 0·3 to 0·4 mm. The hardness of this, compared with that of the white layer, is lower by 200-300 Vickers' units[1]

Accuracy of working[2] This is one of the most important engineering features and is determined by a series of phenomena accompanying the removal of metal. During the first period of approach of tool to workpiece the tearing out (ejection) of metal particles proceeds from the electrode faces. As the tool enters more deeply into the workpiece the discharges, now beginning to take place between the whole of the closely contiguous surfaces, produce a space or clearance S, corresponding to the distance penetrated under the given working conditions. The individual particles and agglomerated groups of disintegrated metal from the working zone, impelled forward into the gap formed, cause supplementary discharges that increase the gap still more by an amount r. Thus the total size of the gap will be the sum of both spaces, i.e. $\triangle = S + r$.

In the working process there is not only disintegration of workpiece but also of the tool, involving the distortion of its original profile. This ultimately leads to distortion of the geometrical form of the worked surface. In the early stages of discharge taking place between the component surface and face of tool, there is little appreciable change in the form of the latter. With slightly deeper penetration of the tool into the mass of the workpiece, in addition to wear on its face or tip, wear begins also on its side surfaces. With still further penetration of the tool its profile becomes more and more distorted, and when the tip emerges from the other side of the workpiece the geometrical form of the worked surface differs sharply from that required. In order that the final shape is approximately that required, working is continued until the tip of the tool extends beyond the limits of the workpiece by an amount equal to 1·5 to 2 times the depth of work.

[1] This must depend on the steel being machined.

[2] Here we consider the inaccuracies inherent only in the electro-spark method; the usual type, such as, for example, errors in preparing the tool, errors in machine design, errors in mounting component and tool, and so forth, are not included.

Thus, in electro-spark broaching there occur, firstly, the formation of a gap enlarging the diameter or width of the worked opening, and, secondly, the distortion of the geometrical form of the worked surface. Therefore the accuracy of working under the given conditions will be determined by the degree of distortion of the profile of the electrode tool and the extent of deviation of the gap formed from a certain mean value. With all other conditions equal, the stability of the gap will depend on variations in voltage in the initial stage of discharge and of the applied voltage.

Fluctuations in the initial discharge voltage cause a corresponding change in the inter-electrode gap, depending on the sensitivity of the control circuit. With increasing depth of work the concentration of disintegrated particles of metal in the working zone is increased, and this in turn causes variation in the size of the gap, even with ideally accurate feed control. Moreover, all voltage variations in the system feeding the electro-spark machines affect the working of the control circuit, and this too involves variation in the size of the gap. The effect of these various factors on the stability of the gap (i.e., on the accuracy of working) cannot be eliminated by any general precaution, and they must be added to the usual inaccuracies (errors in preparation of tool and apparatus, errors in mounting the tool, its auxiliaries and the workpiece, errors in machine design). Table 8 (based on data from OKB MM) shows the deviations in gap size in forming eight holes under uniform conditions.

TABLE 8

No. of hole	Dia. of hole in mm		Gap between workpiece and tool, in mm		Remarks
	Entry	Exit	Entry	Exit	
1	10·51	10·36	0·52	0·37	
2	10·51	10·40	0·52	0·41	
3	10·52	10·39	0·53	0·40	Tool material was brass LS59, Dia. of tool 9·9 mm. Workpiece material was hardened steel (St 50) 4·93 mm thick. Working regime: C=100 mfd, $I_{sh\,c}$= 11·5 amp, U=240 v
4	10·55	10·44	0·56	0·45	
5	10·54	10·45	0·55	0·46	
6	10·53	10·36	0·54	0·37	
7	10·56	10·40	0·57	0·41	
8	10·52	10·41	0·53	0·42	
Mean	10·53	10·40	0·54	0·41	

From the Table it is evident that accuracy in working the hole at entry ($10{\cdot}53\,^{-0{\cdot}02}_{+0{\cdot}03}$) is greater than that of the hole at exit ($10{\cdot}40\,^{-0{\cdot}04}_{+0{\cdot}05}$) and the holes themselves have a certain amount of conicity. Conicity of the hole is explained by the fact that, during formation of the exit, there is a supplementary path for the disintegrated particles which lowers their concentration in the working space, with consequent reduction in the gap between workpiece and tool at the exit of the hole.

By increasing the coarseness of the regime, with specified materials for tool, workpiece and working fluid, the mean size of gap is increased. In Table 9 are given the figures for unilateral clearances (gaps) obtained in working steel 5KhNM under the three basic regime groups.

TABLE 9

Regime used	Side clearance in mm	Tool material
Coarse	0·5–0·6	Brass LS59
Medium	0·2–0·3	Brass LS59
Fine	0·03–0·06	Brass LS59

Other conditions being the same, the chemical composition of materials used in tool and workpiece (Tables 10 and 11) has an appreciable effect on the size of the gaps obtained; and in the case of the workpiece is so marked that even under the fine regime the value of the deviations obtained may often exceed the permitted limits. For example, the difference in size of gap in the working of steels Kh12M and U8A may be 15 microns laterally.

TABLE 10

Tool material	Workpiece material	Side clearance in mm	Working regime
Brass LS 59 ..	Hardened steel U8A	0·25	U=120 v I=4 amp C=60 mfd
Copper	Hardened steel U8A	0·27	
Duralumin	Hardened steel U8A	0·30	
Copper-Graphite ..	Hardened steel U8A	0·34	
Grey cast iron ..	Hardened steel U8A	—	

TABLE 11

Regime	Size of gap in microns in working different kinds of steel with a brass tool		
	U8A	ShKh15	Kh12M
Coarse ..	120	150	180
Medium ..	100	120	135
Fine ..	50	65	65

Therefore in the accurate working of components of different materials it is impossible to use the same size tool. In this case the size to which the tool should be reduced is based entirely on trial with samples or test pieces. The size of the gap does not depend on the dimensions of the worked surface, and hence the accuracy of working becomes greater the larger the dimensions of that surface.

The production by the electro-spark method of cavities and projections having sharp transitions or acute angles is difficult, as these are normally obtained with curvatures (Fig. 7). The reason for this is to be found in the fact that, in forming

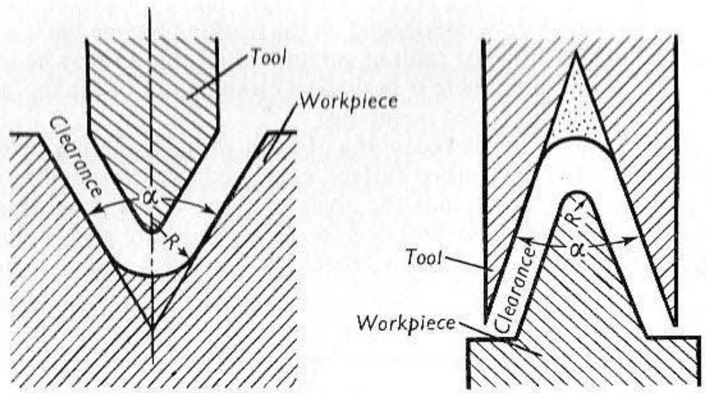

Fig. 7. View of distortion of form of tool in producing cavities and projections

cavities, the tip edge of the tool, engaging with a large area of workpiece, is extensively worn and blunted. Experiments by Cand. Techn. Sci. Volodin showed that the radius of curvature of the cavity does not depend on the size of its angle, and is determined by the material used for workpiece and the working regime. (See Table 12).

TABLE 12[1]

Regime	Size of angle in degrees						Mean radius in mm
	15	30	45	60	75	90	
	Radius of curvature (in mm)						
Coarse	0·30	0·30	0·40	0·40	0·30	0·40	0·35
Medium	0·25	0·20	0·30	0·30	0·30	0·40	0·29
Fine	0·05	0·10	0·10	0·05	0·05	0·10	0·07

TABLE 13[1]

Regime	Size of angle in degrees					
	15	30	45	60	75	90
	Radius of curvature (in mm)					
Coarse	0·20	0·30	0·40	0·60		1·10
Medium	0·25	0·30	0·50	0·60		1·00
Fine	0·25	0·25	0·40	0·60		1·10
Mean for all regimes	0·23	0·28	0·43	0·60		1·07

[1] Data in Tables 12 and 13 were obtained in working steel U8A with a brass tool.

As the tool tip penetrates more deeply into a component in forming a bend or recess, the clearance gap becomes filled up or choked with disintegrated particles of metal and the acute angle at the tip becomes rounded. This in turn causes curvature of the worked surface profile. However, unlike the preceding case, the radius of curvature here does not depend on the working regime but is a function of the angle (cf. Table 13). The radii of curvature in Table 13 may be somewhat reduced if, during working, there is periodical cleaning out of the tool tip recess and removal of the accumulated metal dust.

As was shown above, in the broaching of through holes there is deformation of the tool form and of the worked surface, expressed in corresponding conicity. Depending on working conditions the angle of slope of the cone thus formed varies from a few minutes to several degrees. In Table 14 are given values of the slope angle of the cone formed when broaching steel U8A with a tool of brass LS59.

TABLE 14

Regime	Angle of slope of cone formed
Coarse	1° 30′
Medium	1°
Fine	0° 35′

In most of the cases discussed the degree of distortion of the worked surface, and also the mean value of the gap formed, are decreased as the regime becomes less coarse. From this it follows that, in order to obtain the highest accuracy in working a surface, the electro-spark process should be operated in two or three successive stages involving coarse, medium, and fine regimes. By this means the distortions resulting from working with the coarse regime using a roughing tool are rectified in the successive operations with medium and fine regimes using finishing tools.

The tool. The tool in electro-spark working does not produce chips as with a metal-cutting tool. Its functions are limited merely to the transfer of the energy of discharge to the working zone and its proper distribution along the required contour. As is already known, the breakdown of metal by the method described is connected with electro-thermal phenomena accompanying the discharge; and the suitability of a tool material will be determined for the most part by its thermo-electrical properties (thermal and electrical conductivity).

In principle any current-conducting material may be used for the tool. In practice, however, there are various other considerations connected not only with varying efficiency but with the varying erosion resistance of individual materials. The tool used in electro-spark working is subjected to break-down in the same way as the worked component. Such breakdown is associated in the first place with the heat evolved during discharge, which acts not only on the workpiece but also on the electrode tool itself. In addition to the usual electro-erosive wear, the disintegration of the tool is increased by the abrasive action of the small particles of metal expelled from the working zone by hydraulic impact of the liquid. The wear on the tool, depending on the working conditions and nature of the material of workpiece and tool, ranges from 20 to 250 per cent of the volume of metal removed from the workpiece.

In practical electro-spark working there are several means by which wear on tool can be reduced. Basically these are divisible into electrical (including resistance in the discharge circuit, a finer working regime, varying inductance in the discharge circuit), and technological (choice of erosion-resistant materials, of rational form of tool, etc.) methods. Choice of tool material, as a rule, is governed by the conditions for obtaining maximum disintegration of the anode-workpiece with minimum wear of the cathode tool. Here it is essential to take into account availability, cheapness, mechanical strength of material, and the complexity or otherwise of shaping it into a tool. From data given earlier (cf. Fig. 5) it is easy to show that, according to the conditions of productivity and output, tools made from copper-graphite mix, brass LS59, and copper, are the best.[1]

If the erosion resistance of a tool made of brass LS59 is taken as unity, then the relative erosion-resistance of a tool made of other materials may be expressed by the figures in Table 15.

TABLE 15

Tool material	Relative erosion resistance[2] (relative wear)
Bronze AMZhTs 10–3 ..	1·19
Brass LS62	0·84
Phosphor bronze	0·69
Ferrito-perlitic grey cast iron	0·38
Red copper	0·37
Copper-graphite mass MG 4	0·30

Comparing the data of Table 15 and Fig. 5 one can note the difference in properties of tools made from brasses LS59 and LS62. It was found that the difference in properties of the brasses depended on the percentage content of zinc. Thus, for example, minimum wear was observed with the complete absence of zinc, and maximum when it was present up to 40 per cent. Again, comparison of data in respect to efficiency shows that its maximum corresponds to a zinc content of 30 per cent in the brass. Therefore brass LS69, containing 37-40 per cent zinc, has a high efficiency and high relative wear; whilst brass LS62, containing 5 per cent zinc, has low relative wear and indifferent efficiency. Therefore a tool made of brass cannot at the same time completely satisfy the two basic requirements: maximum efficiency and minimum wear.

From Table 15 and Fig. 5 it is evident that tools made from copper-graphite, brass, and copper, have the highest efficiency with minimum wear. It would seem

[1] Many organizations recommend as material for the electrode grey cast iron.

[2] Erosion resistance is inverse of relative wear. Here the values represent relative wear.

that the best material for the purpose should be the copper-graphite mix, comprising a mixture of copper powder and graphite compacted under high pressure and sintered. The minimum wear and high efficiency in working obtained with the use of a copper-graphite tool are among its important advantages; but complex and difficult technology, and also its poor mechanical qualities, make such a tool difficult to use.

In order to improve the mechanical properties of a copper-graphite tool it is recommended that it is prepared with a cementitious bond, according to the following procedure: The mix comprises copper 85 per cent, aluminium 2·5 per cent, well wetted graphite 2·5 per cent, and a cement 10 per cent, carefully mixed with water to bring it to the consistency of a paste. The mix is poured into a press mould and compacted under a pressure of 1000 to 1500 kg/cm²; excess water is forced out and the mass reduced in volume by, say, two-and-a-half times. The formed tool, having a mirror-like surface and high strength, in respect to wear resistance and efficiency, is in no way inferior to a tool made from the usual copper-graphite material.

But despite this the technology of making a copper-graphite tool remains very complex, and its manufacture is not always feasible since its mechanical processing needs suitable experience. Therefore under industrial conditions materials which have a lower erosion resistance and life, and, at the same time, are more easily available and workable, are widely used. The best among such materials are brass and red copper which combine a high electro-erosive quality with good mechanical strength and ease of working.

Recently the OKB MM has proposed a new material for the tool, comprising an alloy of copper and cadmium (96-97 per cent Cu and 3-4 per cent Cd). Tools of this material, known as BKE, have about one-fourth the rate of wear, as compared with brass, and increase the rate of working by 20-30 per cent. Maximum rate of working with minimum wear are not always the decisive factors governing the selection of tool material. In working dies with complex impressions, using a tool of similarly complex profile, the most important consideration is the economy of the method that can be used in shaping its contour. From these considerations the use of tools made by stamping and casting are indisputably more suitable than those made by forging or mechanical methods. Therefore in a whole series of operations such as, for example, the production of forging, punching, embossing, and other dies, electrodes of cast and pressed aluminium, cast-iron and even steel have been widely used.

The ability of the spark discharge to reproduce accurately the contour of one electrode on the other determines the geometrical form of the tool, which is the negative counterpart of the impression required in the worked surface. For example, in producing cylindrical, square, or hexagonal holes, the tool is made accordingly in cylindrical (round), square or hexagonal rod. It has been pointed out earlier that, compared with the dimensions of the tool, the size of the worked surface obtained is larger by a definite value depending on the working regime and electrode material. This fact must invariably be considered in determining the dimensions of the cross section of tool; and the latter is always of smaller dimensions compared with the nominal size of the worked surface. For example, figures indicating reduction in size of tool in working carbon steels with copper-graphite and brass tools are given in Table 16.

For each specific case of working the absolute value of reduction in size of tool is established by experiment. Depending on the length of the working part an

TABLE 16

Working regime	Extent of reduction of tool, laterally, in mm
Coarse	0·5–1·0
Medium	0·2–0·5
Fine	0·05–0·06

allowance is made in the tool for compensating linear wear and rectifying the inevitable appearance of conicity. The amount of this allowance in broaching through holes of 3 mm diameter and more is usually one and a half to twice the depth of the broached hole. Experience shows that the wear of a tool depends on the extent of the worked surface, and in broaching holes of less than 3 mm diameter amounts to 300-500 per cent of the quantity of metal removed from the workpiece. In working small holes this makes it necessary to extend the length of working part of the tool still more: the amount of allowance in such case is 4·5 to 7·5 times the depth of the hole broached.

The efficiency of electro-spark working is determined not only by the electro-erosive qualities of the tool but also by its design and form, which is closely related to the nature of the work to be done. Depending on these design features all tools may be divided into two basic categories: those with complete profiles and those with segments of profiles (Fig. 8). Tools in each of these two categories

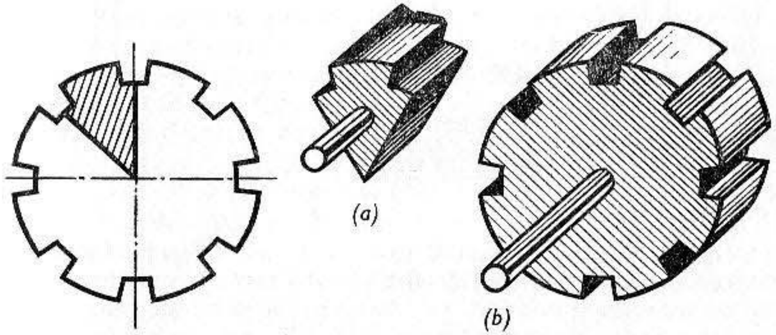

Fig. 8. Elemental (*a*) and full profile (*b*) tools

may be again sub-divided into hollow and solid groups (Fig. 9). Other tools with slanting grooves or slots (Fig. 10), intermediate recesses (Fig. 11), and open recess (Fig. 12) are available, depending on the purpose and nature of the work to be done.

Segmented tools are used for working complex impressions with not very high accuracy and large surfaces for which the provision of fully profiled tools is expensive and troublesome. Fully profiled tools are used for forming simple surfaces with a high degree of accuracy. The use of such a tool is economical only when it can be made by stamping or casting methods. Solid or massive tools are intended for forming blind holes and recesses, and for fine through holes and narrow slots.

Tools with slanting slots, intermediate recesses, and a free or open recess, are used to facilitate the removal of pyrolytic gases and disintegrated particles, and

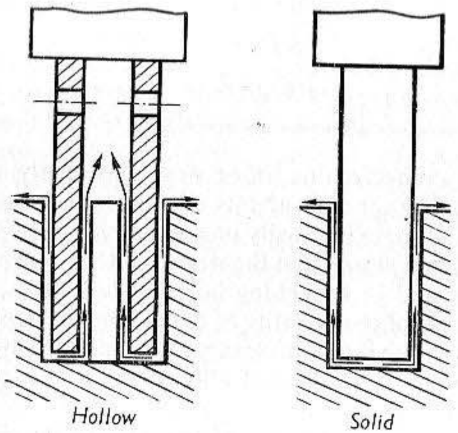

Fig. 9. Hollow and solid tools

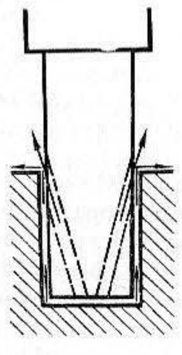

Fig. 10. Tool with sloping grooves

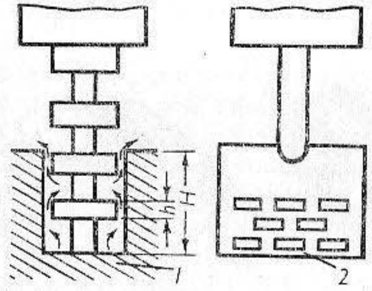

Fig. 11. Tool with spaced recesses. 1—cylindrical; 2—flat

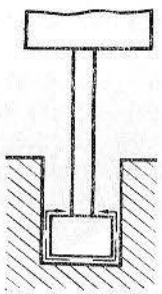

Fig. 12. Tool with open recess

to raise the intensity and accuracy of working in broaching blind deep holes and recesses. Hollow tools are employed for forming through holes and recesses of cross-sectional area above 30 mm². The fact that removed metal accumulating within the contour of the tool is not subjected to unnecessary dispersion, the use of a hollow tool permits reduced consumption of energy and shorter working time. Moreover, such a tool makes it possible to flow the liquid through the working space, and this, in turn, increases intensity of working.

The method of preparing the tool depends on the properties of the material used, its design and purpose. In Table 17 are shown the methods employed for making tools of different materials. Tools of simple form are preferably made from the copper-graphite mass in which the tool is simply pressed from the crude mass with cement binder; but it is both pressed and sintered when made from the ordinary material. In using a prepared copper-graphite mass the tool of required profile is shaped (cut) out, turned, sawn, etc. Tools of brass, copper, aluminium and cast-iron may be made by any of the methods generally employed in shaping these materials, such as casting, stamping, mechanical working, cutting out with subsequent soldering.

TABLE 17

Method of making tool	Tool Material						
	Cu-graph	Cu-graph and binder	Brass LS59 LS62	BKE	Copper	Cast Fe	Aluminium
Casting	*	*	†	†	†	†	†
Stamping (pressing)	*	*	†	†	†	*	†
Mechanical working	†	†	†	†	†	†	†
Bending and soldering	*	*	†	†	†	†	†
Pressing and sintering	†	*	*	*	*	*	*
Pressing	*	†	*	*	*	*	*

† = method used; * = method not used.

Cast tools of low accuracy design are rarely used. Stamped or pressed tools are more widely employed. In a number of cases pressed or stamped components may be used with subsequent reduction of dimensional fitting or bench work. Profile-rolled brass, copper, aluminium, and bronze are widely adopted as semi-fabricated tool material and frequently for the tool itself. The tool may be machined by turning, milling, planing, and grinding, depending on its type and the accuracy required in its form.

A tool for cutting slots of varied forms and through holes of complex shape is made by cutting out from sheet metal, and subsequently bending and soldering. The sheet metal used should not have local thickening as this causes irregular wear of tool. In order to ensure dimensional accuracy in a tool made in this way it should be sized in a special jig. Tools of sheet brass are deformed when working under conditions in which lateral discharges are produced, thus reducing the accuracy of working. In order to avoid this the sheet brass must be tempered before conversion into electrodes. To facilitate the escape of gases accumulating in the inner recesses holes are drilled in the upper parts of hollow tools. For excluding fracture or splitting of the worked surface when the tool is "biting" into the workpiece the leading surface of tools of all types should have a chamfer or cone. Tools are provided with tailpieces as means of attachment in the form of cones or cylinders mated with a taper, colet, or chuck type of holder. The choice of rational design, material, and construction of a tool is determined by the specific conditions of working and production.

Methods of increasing efficiency. At the present time the efficiency of the electro-spark working of the usual constructional steels is somewhat lower than that attainable in mechanical working. The maximum rate of machining of the electro-spark method with steel is 330 mm³/min (cf. data Table 5). In electro-spark working the liberation of energy and related removal of metal are of a cyclic nature. The complete cycle may be divided into two periods: the charging of the condenser, and its discharge. In accordance with results obtained by Cand. Techn. Sci. D. T. Vasil'ev the time required for the interval and charging of the condenser is 99·3 per cent of the total cycle. Thus, for electro-spark working a machine is only doing useful work during 0·7 per cent of total time.

The efficiency of working is therefore higher the shorter the time required for charging and the interval between discharges. The potential on the condenser increases rapidly at first, and during the first half of the charging time attains a value equal to 0·9 of that of the applied voltage. Despite some loss in the energy of discharge (about 19 per cent) the discharge nevertheless takes place more expeditiously at that precise moment than when the condenser potential reaches its full magnitude. This is so, since, shortening the time for charging, i.e., increasing the number of discharges, compensates in full measure the losses due to incomplete charging of the condenser. This presents a method of raising the efficiency of electro-spark operation.

In practice the method of enforced discharge is realized by closer approach of electrodes than the prescribed size of gap. The electrodes are suitably positioned by means of corresponding adjustment of the control circuit. The correct adjustment of such control circuit can be determined by readings of the thermal or condenser voltmeter included in the discharge circuit. With an optimum electrode gap the voltage of the discharge circuit is 0·7 to 0·85 of that of the charging circuit. It is also possible to judge the correctness of the adjustment by the value of the ratio of working current to the short-circuit current, which, according to the kind of working regime used, should be 0·65 to 0·8.

In the usual arrangement of working the discharges follow each other in series, and parallel discharges are usually excluded. There is no doubt that efficiency of working would be considerably increased by creating conditions for the simultaneous production of several discharges. This could be obtained by changing the usual single-circuit set-up for a multi-circuit type using a composite tool. In the arrangement shown it is evident that each electrode of such a tool is connected with the cathode of a single condenser, which is charged up through a single resistance. In order to prevent short-circuiting between the electrodes of the composite tool they are insulated from each other by layers of paper (wax or tracing, blue print, etc.) with a total thickness of 0·2 to 0·25 mm. During operation of the machine and in proportion to the wear of tool the paper is gradually burnt up.

It is easy to see that the total efficiency of working according to this arrangement is the sum of the efficiencies of individual circuits, and is increased *pro rata* with their number. In practice machines of thecontact type are preferable for the multi-circuit scheme. In such cases the energy of each circuit is most efficiently used, since the possibility of extensive short-circuiting between parts of the electrodes of the composite tool is excluded. The feed control of machines of the non-contact type does not always ensure normal working of the tool composed of several electrodes, and a method of electronic control is used, as developed by Cand. Techn. Sci. D. T. Vasil'ev. In this arrangement (Fig. 13), electrodes E_1 and E_2 comprising the tool are firmly attached to the spindle of the machine with solenoid control and a separate condenser unit is in circuit. The solenoid S winding is connected to the anode of a triode valve type UO-186. The anode current of this valve is controlled by variation of potential between grid and filament. Control of supplementary grid voltage from supply B and of resistance values r_1 r_2 R_1 R_2 permits selection of working regime in any part of the valve characteristic, and therefore the optimum operation of machine. In short-

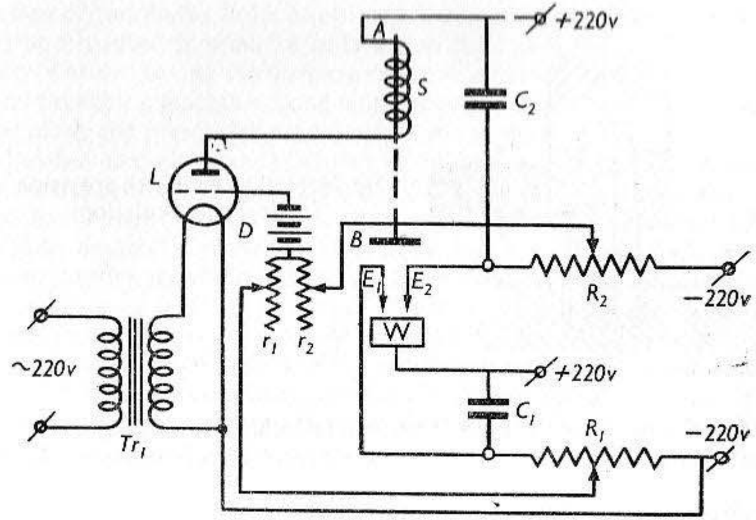

Fig. 13. Set-up of electro-spark circuit with electronic control

E_1 E_2—electrodes of composite tool; W—workpiece; AB—spindle; S—solenoid; L—valve UO-186; C_1 C_2—condenser unit; R_1 R_2—rheostat; r_1 r_2—control resistances; Tr_1—transformer; D—control circuit (valve) battery

circuiting one of the electrodes the anode current of the valve is increased, and also that of the solenoid control. Increasing current in the solenoid windings increases the force on the core spindle and this breaks the short circuit. For normal working the current strength in the solenoid S should be 120 to 200 mA, with 20 000 windings and a wire diameter of 0·35 mm.

The most convenient and simple method for increasing efficiency is the inclusion of a choke with iron core in the charging circuit. In this way the supplementary inductance of the choke, by permitting increased voltage of the initial discharge, creates conditions for more effective removal of metal. In this case, according to results obtained, efficiency is increased 25 to 30 per cent. The choke is a coil with 450-600 windings of wire 6 to 7·5 mm in section wound on an iron core (closed). For machines of 2 to 5 kW power the inductance of the choke would have a corresponding value of 0·05 to 0·25 henry.

Rate of machining may also be increased by various techniques, e.g. the use of hollow tools with a supply of working fluid across the erosion gap. Hollow tools, as already mentioned above, permit increased machining rate owing to the reduction in total quantity of metal subjected to disintegration; and the existence of internal space improves the conditions for removal of the disintegrated particles from the working point, and thus steps up efficiency. As the tool (broaching) penetrates more deeply this removal of metal particles becomes more difficult, and their concentration in the erosion gap is greater, causing a sharp decline in working capacity, even when using hollow tools. To compensate for this loss of efficiency forced circulation may be used, with a special support provided for the hollow electrode (Fig. 14). According to results from a number of sources the injection of the fluid across the tool gives better performance than with pumping or other means.

This provision of forced circulation is only advisable in deep working exceed-

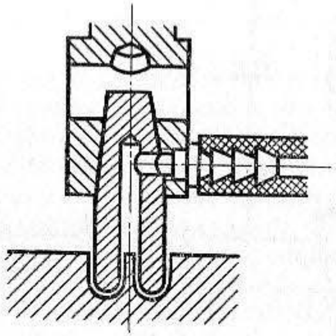

Fig. 14. Hollow tool with provision for forced circulation

ing 1·5 to 2 diameters of the hole. With small depths of broaching and with small areas of working (50-100 mm²) the effect of forced circulation is negligible.

BROACHING OF HOLES

The broaching of holes is one of the most common operations using the electro-spark method. The rate of cutting holes in tool materials has hitherto been very low; but now the possibility of working metals by the electro-spark method is independent of their hardness and plasticity (toughness). The absence of the need for rotary movement in the tool used is an advantage in forming shaped and cylindrical holes in components of tempered steel and hard metals (alloys or sintered carbides), in the production of holes of curvilinear axis, and those of small diameter.

All holes broached by the electro-spark method are basically divisible into two groups: through holes and blind holes. In each category, depending on the form and depth of broaching, the holes may be sub-divided into cylindrical, shaped or irregular, curvilinear, of normal depth (up to 3 or 4 diameters), and deep holes (of more than 4 diameters). The difference in broaching through and blind holes with an area of 30 to 50 mm² lies in the fact that, in order to increase the efficiency of the process, through holes are worked with a hollow tool. Moreover the sizing of a through hole is effected with further forward movement of the unworn (top) part of the tool to the extent of 1 to 1·5 the depth of broaching. A blind hole is sized in a few successive passes, with periodic truing of face of tool.

In electro-spark broaching the required contour of the hole is obtained from copying the tool profile. The broaching of cylindrical, irregular (shaped) and other holes differs merely in the form of tools used. According to some authors imparting a turning movement to the electrode somewhat shortens the time of broaching. It is understood that this can be done only in the broaching of round holes.

Until recently the boring of holes with a curvilinear axis by the usual methods of mechanical working was regarded as an impossible engineering operation. If such holes were required, they were as a rule replaced by a combination of rectilinear holes, the drilling of which through the body of the workpieces in some cases reduced their life.

With the introduction of the electro-spark method such operations became feasible, facilitating the solution of quite a number of design problems. For the production of curvilinear holes a tool with a curvature equivalent to that of the hole to be broached is used. In such a case the tool is fed or advanced in the direction of an arc having the same curvature. Curvilinear holes are broached on the usual broaching machines fitted with special attachments ensuring electrode advance along the prescribed arc of curvature or spiral.

As already stated above the efficiency of the process is markedly lowered with increase in depth of working. In the case of deep holes this involves the use of a pumped liquid supply across the erosion gap. Where this is not feasible (with slits or slots, or small diameter holes, etc.) the tool is given an axially oscillating movement. During oscillation, when the electrodes draw together, the fluid and erosive break-down products are expelled from the hole, and during the reverse movement fresh liquid is pumped into the working gap from the tank.

In machines of the contact type the oscillating movement of the tool is derived from a special electro-magnetic mechanism—a vibrator. In machines of the non-contact type with solenoid and electrodynamic controls the vibratory movement of spindle and tool is produced by over excitation of the windings of the follower system.

In broaching holes in components which are to undergo heat treatment a combined technique of "lead and follow" is used. Before heat treatment, holes are mechanically drilled in the component with an allowance for subsequent electro-spark broaching. The amount of such allowance is determined in each case according to the individual features of the worked component. This method of preliminary drilling facilitates removal of the products of erosive disintegration and permits much more efficient production in broaching deep holes. The relation shown in the curves of Fig. 15 indicates the efficiency achieved in broaching previously drilled continuous holes. In deep broaching, when the

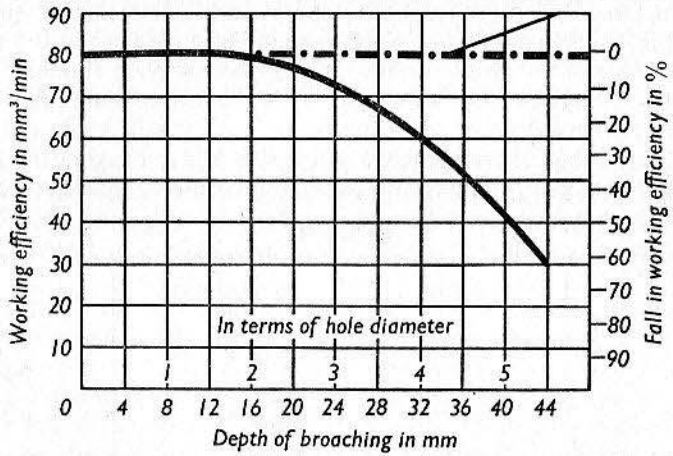

Fig. 15. Relative efficiency of working in broaching continuous and previously drilled material

Workpiece material—acid resistant cast iron; tool material—brass LS59; working regime: U—voltage 220; short circuit current—9 amp; capacity—74 mfd; diam. of holes—8 mm.

extent of the path traversed by the particles thrown out from the working zone is considerable, operating efficiency is increased by reduced viscosity of the working fluid, so that for deep holes the working fluid is kerosene.

It was pointed out earlier that excessive increase in the short-circuit current causes intensive formation of gas in the working zone, with almost complete displacement of the working fluid therefrom, and interruption of steady operation. The strength of the limiting short circuit current (or power delivered by the electro-spark machine) increases with increase in the working area, as the volume of the inter-electrode gap is then enlarged, and, correspondingly, the quantity of gas diminished. Therefore the area of working is a primary consideration in selecting a machine suitably powered for broaching specified holes.

In broaching holes of 20 mm² area (5 mm diameter) with machines of 4·4 kW (operating regime: U = 220 v, I_r = 22 amp, and C = 300 mfd) it is already seen that the operating stability is disturbed. It is found in practice that stability in broaching holes of area up to 20 mm² may be ensured only under conditions where the power of the machine does not exceed 0·8 to 1 kW. Holes of area greater than 20 mm² may be broached more effectively with a power of 4·4 kW than with only 2 kW. However, if the power required in breaking down a unit weight of metal is considered, then the expenditure of such power may be regarded as desirable only in broaching holes of 200 to 2000 mm² in area.

Thus, in relation to the size of the holes to be worked, the following figures for power of machines (in kW) may be taken as a guide:

For holes from	1 to 20 mm²	0·8 to 1 kW
,, ,,	20 to 200 ,,	1·5 to 2 ,,
,, ,,	200 to 1600 ,,	4·4 ,,
,, ,,	above 1600 ,,	4·5 ,, and over

The broaching of holes of small diameter (below 0·5 mm) by the usual methods is troublesome due to insufficient rigidity of tool; and therefore for such holes special guide bushes or sleeves with internal diameter somewhat exceeding that of the tool are employed. Glass tubing is generally used as material for the sleeve, and is heated and drawn out until the required inside diameter is obtained. The sleeve is attached to a conductor plate mounted at a distance of 0·5 to 0·8 mm from the surface of the worked hole. This conductor plate should be made of non-magnetic material to facilitate removal of the accumulating particles.

In order to increase accuracy of work, reduce wear of tool, and lessen its deformation, small holes are broached with a specially fine regime (see Table 18). However, the use of such fine regimes does not ensure complete removal of the

TABLE 18

Diameter of hole in mm	Voltage v	Capacity in mfd	Current, short-circ. in amp.
0·1	25–40	0·15–0·5	0·1–0·5
0·2	40–75	0·5–2	0·2–0·75
0·3	40–100	0·5–4	0·3–1·0
0·4	75–100	1·0–5	0·4–1·2
0·5	75–125	2·0–8	0·5–1·5

disintegrated particles, which, accumulating in the working zone, lower efficiency and also deform the broached hole. Conditions for the removal of these particles in such cases are improved by imparting an oscillatory movement to the tool or to the workpiece.

Broaching is usually done on machines of the contact type (LV-14), described later. It is also possible to use non-contact machines of the type of the OKB MM bench machines. In this case, in order to avoid deformation of the tool during accidental vibration during broaching, the spindle should be balanced by counterweight and also hand-braked. It is preferable to use tungsten or brass wire as material for the tool in broaching small holes. To prevent fracture at the entry of the hole the working end of the tool should be drawn out to a taper. The length of the tapered part is generally 1·3 to 1·5 the depth of the broached hole. In order to ensure accuracy in broaching holes the wire electrode is straightened by heating and drawing. All machines used in broaching small holes are provided with a unit for straightening the wire; and as a rule the working fluid is kerosene.

PRODUCTION OF PRESS-TOOL DIES

Preparation of the working profiles of dies for stampings in sheet and bar, even under the conditions of modern engineering, is a very troublesome operation. A large amount of hand fitting and bench work by highly skilled workers is necessary. In preparing these die profiles (mostly matrices) by the electro-spark method hand-work is replaced by mechanization, and cost is reduced. This method also improves the mechanical properties of the working surface of the dies and their stability in operation, as compared with dies produced by mechanical means. The life of the dies in some cases (punching and shearing) is increased two to two and a half times, and is practically unchanged after regrinding.

Increased die life is explained by the fact that, after heat treatment, the decarbonized surface layer is removed in electro-spark working. Furthermore, with this process, usually carried out in kerosene, the working surface of the die is strengthened and toughened by the formation thereon of a considerable amount of iron carbides. Electro-spark working follows heat treatment, and therefore the risk of thermal damage is excluded. This is especially important in the production of combination and compound dies which have thin sections in the working impression.

Preparing working profiles of pressing and blanking dies. The formation of the contour within the die opening of a pressing or blanking die consists essentially in broaching shaped holes through the block. In such cases the following procedure is usually followed. A preliminary profile is marked out on the block which contains the necessary assembly holes, and as far as possible these are drilled by conventional methods. The die block undergoes heat treatment, is ground over the base surface, and is then ready for working the cavity contour. The workpiece is fastened to the table of the machine so that the surface containing the cavity is at the bottom of the tank. By this means the required taper of the cavity wall is obtained in the broaching operation. After fixing the workpiece to the table of the machine a tool of the corresponding profile is attached to the spindle. The tool should be mounted with special care, having due regard to the perpendicular position of its axis in relation to the worked surface or plane of the die block. Permitted deviation should not be more than 0·03 mm per 100 mm of length.

In dies for blanking or pressing it is particularly important to ensure co-axial alignment of the die opening and punch and also uniformity of the working clearance between these. These conditions can only be met when the accuracy of working of the electrode tool is within 10 to 30 microns and is operated in common with the working of the die punch. This can be done if the active punch is worked to finished dimensions with a piece of brass soldered to its end, and this is subsequently used as tool. The length of the brass tool is usually not less than 2·5 the thickness of the die block broached.

In operation, the working punch with soldered brass tool is fastened to the spindle of the electro-spark machine; and when broaching of the hole is completed the tool is unsoldered and the punch and die are assembled. The method described, using working punches, should be specially recommended for the production of cavities in multi-punch dies. In this case the punches with the soldered on tools are mounted in a previously prepared punch-holder, which is fastened to the spindle of the machine, and all the holes are worked simultaneously. As the die block is fixed in the machine with the ground face downward the punches used for processing the cavities are mounted in the holder the reverse way in order to secure coincidence of the holes produced with the punches when assembling the die.

Broaching the die cavity in the die block comprises three stages:

(1) Working with coarse or medium regime (cf. Table 19) which is completed when the end of the tool emerges from the opposite side of the workpiece; care being taken to ensure that the angle of slope of hole formed is kept within $1\frac{1}{2}°$ of hole axis (cf. Table 19).

(2) Sizing of hole to finished dimensions, using the fine regime, with angle of slope of a small part (3 to 4 mm) of formed holes to axis of 30′-40′.

(3) Sizing the die opening with use of a very fine regime.

A hole is usually sized with a regime in which the extent of clearance obtained does not exceed that of general engineering practice, say of 0·1 to 0·2 mm. A series of clearance values obtained in broaching with a brass tool the steels most suitable for the production of dies is given in Table 19.

TABLE 19

Working regime	Electrical parameters			Clearance in working steel			Slope angle (axial)
	Voltage	Current	Capacity				
	v	amp	mfd	U8A	ShKh15 (in microns)	Kh12M	
Coarse	100	30	600	120	150	180	1° 30′
Medium	100	15	200	100	120	135	1°
Fine	100	5	10	50	60	65	35′
Very fine	100	0·25	2	40	45	50	20′

From the Table it is clear that alloy steels are less erosion resistant and produce larger clearances than a carbon steel. Therefore in changing or replacing the material of the die block it is impossible to use a tool of the previous dimensions, as the difference in size of the clearances formed may produce hole dimensions exceeding the permitted limits. In order to shorten the time of broaching die cavities it is as well to use the electro-spark method in conjunction with the mechanical, in which the centre of the hole is drilled or milled out, before heat treatment. If the area of the hole is small and such an operation becomes impossible it is necessary to resort to drilling of one assembly hole only. The removal of centres in dies with irregular profile is more conveniently done by the electro-spark method, using a hollow tool. In this case, with the subsequent completion of the electro-spark working, a lateral allowance of not more than 0·5 mm is left.

Production by the electro-spark method of dies for closed die stamping. This may be regarded as a particular case of forming blind holes of irregular depth and width. In this case the tool does not penetrate right through but only to the depth specified on the drawings. The technical method and series of operations involved in preparing dies for closed die stampings are:

(1) Cutting the die blank and its subsequent shaping,
(2) Planing or milling,
(3) Heat treatment,
(4) Grinding the base,
(5) Marking out,
(6) Electro-spark working by hand.

For producing the die by hand three different sized tools are needed—roughing, semi-finishing, and finishing, corresponding to coarse, medium and fine regimes of working. In repetitive production of dies, the tools used in working with fine and medium regimes can be used for coarse working after suitable truing by filing. The size of the roughing tool, in plan, is 0·2 to 0·3 mm less than the corresponding dimensions of the die impression, and the semi-finishing tool is 0·05 mm less. The largest dimensions of the finishing tool should not exceed those of the impression profile reduced by the size of the allowance for finish plus values of lateral clearance for the final finishing regime.

To allow for the wear of a brass LS59 tool the length is usually made one-third the depth of the impression. But in designing and making each individual tool the allowance mentioned requires corresponding correction determined experimentally in relation to the complexity of the impression contour, material of die and tool. For individual dies the tool is made by hand by mechanical means; but in the case of repetitive work, is is made by stamping or shaping the worn material, and then filing to the required dimensions. Accuracy of the tool made is $\pm 0{\cdot}03$ mm. Control is achieved by means of templates or gauges.

The hand working for die impressions intended for stamping small components is done under regimes shown in Table 20.

TABLE 20

Regime	Characteristics			Specified pass
	Volts	Amp	Mfd	
Coarse	150	2·5	25	Removal of 50% depth allowance
Medium	120	1·5	5	Removal of 30% depth allowance
Fine	80	1·0	2	Finish to dimensions

In practice one begins with a fine regime (proceeding as in pre-working) then changes over to the coarse regime, and finally through an intermediate regime returning again to the fine working.

In order to shorten the time of working by hand and to reduce the wear of the tool used, when preparing dies for medium size forgings weighing 0·05 to 5 kilos, the die block is drilled or milled, with allowances left for subsequent spark working of not more than 1·5 to 2 mm (lateral). Moreover, in dealing with such dies it is preferable to use more effective regimes, as shown in Table 21.

TABLE 21

Regime	Characteristics		
	Volts	Amp	Mfd
Coarse	100	10	100
Medium	100	5	50
Fine	100	3	10

In several cases the process of electro-spark working of the die impression may be divided into two or more operations undertaken with an incompletely profiled tool. Thus, for example, the production of a die for the hot stamping of thumb nuts (Fig. 16) is divisible into two parts carried out with two differently profiled tools (Fig. 17), namely, the wings or ears are made with tool 1 and the barrel-shaped recess, with tool 2.

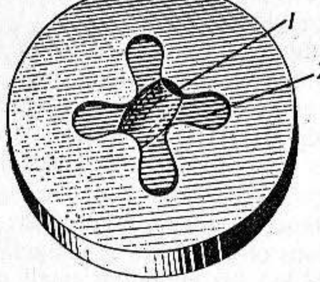

Fig. 16. Matrix of die for stamping thumb nuts
1—body of nut; 2—wings of nut

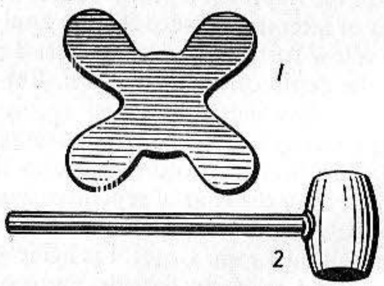

Fig. 17. Tools for working matrices of die for thumb-nuts
1—tools for wings of nuts
2—tool for body of nut

In most cases for the production of large die impressions for components exceeding 5 kilos the use of the electro-spark method is not economical owing to heavy wear of the large and expensive tool and the relatively low efficiency.

One variety of use of the electro-spark method in tool die production is the reconditioning of worn dies (especially forging and bending). It comprises a preliminary grinding of the joint faces and subsequent recessing of the impression by a finishing regime, as shown in Table 22.

TABLE 22. *Operations involved in reconditioning dies*

Mechanical method	Electro-spark method
1. Annealing 2. Planing form or part of it 3. Preparing form (figure) 4. Heat treatment 5. Finishing	1. Top grinding to remove cracks 2. Recessing figure or form with a new electrode tool

If the number and nature of the operations required in reconditioning dies by the mechanical and electro-spark methods are compared the advantage of the latter is indisputably evident. A comparative evaluation in terms of expenditure of the efficient use of the electro-spark process in the production of dies for small and medium forgings (according to results of Cand. Techn. Sci. E. A. Volodin) is shown in the following approximate figures: reduction in cost of power 15-40 per cent, reduction in labour requirements 10-30 per cent. The efficiency of this method may also be shown by data from the Krasnogvardeets factory in Table 23.

TABLE 23

Items etc. compared	Different methods of producing forging dies		
	I	II	III
Working discharge (mean)	1·1	4·9	4·8
Fitting (bench) work in hours	23	13	6
Life of dies in number of forgings	3500	4500	7500
Cost (Kopeks)[1] per forging	2·1	1·4	0·9

[1] 10 Kopeks are equivalent to approximately 2½d.

In the first method the dies were produced by mechanical means followed by bench work; in the second the dies were made by stamping, with the use of a so-called master die; and finally, in the third method, the electro-spark working was used.

CUTTING OF CHIP-CURL GROOVES ON TOOLS FITTED WITH TIPS OR FACINGS OF HARD METAL: RECONDITIONING AND REPAIRS

In the high speed cutting of steel with hard metal tools a long continuous chip may be produced which makes lathe operation unsafe and is difficult to remove. There are a number of methods for obtaining a short curled chip. One of the most widely used is that of forming chip-breaker grooves on the front face of the tool. In practice efficient and satisfactory formation of these grooves in tools of hard alloy (carbide) is only possible by the electro-spark method, since the adoption of abrasive means for this purpose causes crack formation in most cases, thus reducing the life of the tool. In small factories with low consumption of cutting tools the bench type machine of the OKB MM may be used for producing chip-breaker grooves in cutting tools by the electro-spark method. On this machine up to 150 tools may be dealt with per shift. For larger establishments which need large quantities of grooved hard metal tools a special large capacity electro-spark machine is used.

A cylindrical brass or copper tool attached to a special mandrel is used for forming the grooves. The radius of tool required to produce a groove of given size is found from the formula: $R_{tool} = \frac{r_{gr}}{1+k}$ where k is coefficient of wear of tool, being 1 for copper and 2·5 for brass. The work is done in kerosene or transformer oil, with regime of: 200 v, short-circuit current of 1·5 amp, and capacity of 25 mfd. In such a case the time of producing a groove of 2 mm in width and 1·5 mm in depth is 0·5 to 1·5 min, depending on the length of the tool edge. The chip-breaker groove is formed as follows: the mandrel with tool is fastened to the spindle of the machine and mounted on the table; the tank is filled with working fluid; the required electrical system is established; switching on the corresponding power source provides the voltage for the discharge circuit, and the groove is formed.

In order that no time is lost after treatment of each tool in removing and mounting the electrode-tool a long electrode is used, and as this becomes worn the cutting tool to be treated is placed under its unworn part. After using up the whole of the working part of the electrode tool it is turned through 180° in the holder, and work continues with its opposite side.

Reconditioning work involving such operations as the removal of a broken tool (screw tap or drill) and of pins, keys, bolts, etc., left in the machined components, is successfully accomplished by the electro-spark method. For the removal of broken pieces of tool brass electrodes are used having a cross-section somewhat larger than that of the broken tool core (screw tap or drill). In working, the core of the broken tool is fragmented and the pieces may be easily removed from the component body. In order to increase stability or working life whilst carrying out this operation the working parts of the electrode have the form of an inverted cone (Fig. 18a). Conicity is kept within the limits of 1/20 to 1/50. In

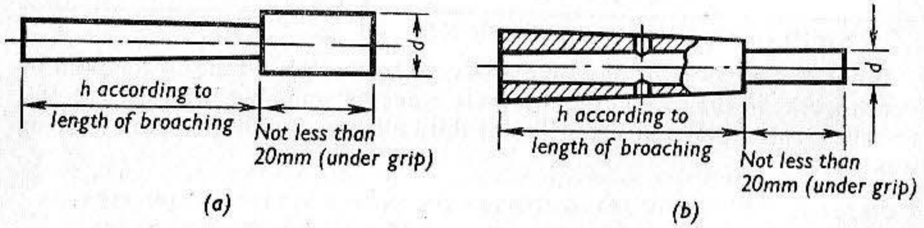

Fig. 18. Special electrode tool

(a) electrode-tool for extracting small tool
(b) electrode-tool for extracting large tool

order to break up pieces of large tools that have become stuck the use of a hollow electrode (Fig. 18b) is desirable. For removing pins, keys, bolts, etc., the electrode has a tetrahedral or hexahedral form. After such an electrode has made a hole in the end or face of the component it may be extracted from the workpiece by means of a socket wrench. Such a method may be used also in removing screw taps and drills.

Since, in such operations, the efficiency of working has no great significance, water may be used as the working fluid. The disintegration of a broken tool or component in articles of small and medium size is done with complete immersion of the article in the working liquid. If the article is so large that it will not go into the bath of the machine then small local baths are used attached to the surface of the article itself by some kind of adhesive, e.g., a nitro-filler. If in such cases a broken piece of tool gets stuck in a through hole its lower outlet should be plugged.

The operating regime is determined by the size of the tool to be removed and from considerations relating to broaching holes as previously stated. In order to make the process safe when removing tools by means of small local baths it is recommended that the working voltage be reduced. OKB MM have designed a special single-regime machine working with the following electrical parameters: 24 volts, 24 amp (sh c) and 6 mfd.

TOUGHENING OF METALS

When producing a discharge in air between an electrode of hard metal or graphite and a steel article the surface layer of the latter acquires a new quality: increased wear resistance. At the present time this effect is widely used for creating wear resistant surfaces on the working parts of tools and machine components. Increasing the life of a cutting tool with the aid of electric discharges became known as electro-spark strengthening. In this process the article to be toughened is the cathode, and the other electrode (hard metal or graphite) is the anode in the usual electro-spark arrangement.

The high wear resistance of the surface layer of metal toughened by this method is associated with the finely dispersed carbides contained in this layer. Formation of the carbides is explained by diffusion of elements of the toughening electrode in the surface layer of the treated component. Increased wear resistance of the surface layer is also promoted by the reaction of a metal component with atmospheric nitrogen (a special form of nitro-cementation) which takes place during discharge, and by extra local heating characterized by rapid rates of heating and cooling.

The toughened layer is hardly affected by the usual etching agents, but owing to its insufficient thickness cannot be used as an anti-corrosive coating. Owing to their small thickness the toughened layers are not subjected to further mechanical treatment; the surface can only be finished with boron carbide, using cast-iron laps, or fine-grained abrasive blocks. The process of electro-spark toughening is of the contact type, and for closing the interacting electrodes special contact block-vibrators are used.[1] Movement of the contact vibrator with the toughening electrode relative to the surface to be treated is done by hand. In some cases, for example in toughening a body of rotation, the feed mechanism of a metal-cutting machine may be used for this purpose. The use of mechanisms for moving the contact vibrator (the rate of movement being determined for each individual case by experiment) makes it possible to obtain a more uniform and dense toughened layer. In using the hand method density and uniformity of the toughened layer depend entirely on the experience of the operator.

The following factors affect the useful properties of the toughened layer: physico-chemical properties of the material of the toughening electrode; elec-

[1] The construction of the vibrators is described in Chapter III, p. 55.

trical regime of working (voltage, capacity, and strength of charging current); surface constitution of the article treated; duration of the toughening process; mechanical parameters of the process. The standard hard metals and in some cases graphite Mark EG2 are used as electrode material. Alloys T15K6, T30K4, and T60K6 give a more wear resistant layer than do VK3, VK6, VK8. Tools intended for finishing work or for measuring instruments are toughened with graphite which gives a better surface finish. Depending on the quality of the surface finish and thickness of the toughened layer the electrical regimes may be provisionally divided into three groups (Table 24).

TABLE 24

Regime	Voltage v	Capacity mfd	Current sh c amp	Thickness of layer mm	Class of finish GOST 2789–45
Fine ..	50–80	30–60	0·25–0·8	up to 0·01	7 to 5
Medium ..	80–120	60–150	1–2	0·01–0·04	2 to 5
Coarse ..	150–220	150–350	2–3	0·04–0·09	2 and lower

In a number of cases a specially fine regime may be used, with capacity of the order of 2 to 6 mfd. The optimum working regime is usually determined by the design features of the tool and conditions of its use. The coarse regime is established from a consideration of the maximum permitted for the given material of the toughening electrode (Table 25).

TABLE 25

Electrode material	Parameters of maximum permitted regime		
	Voltage v	Capacity mfd	current sh c amp
Alloy T15K6	220	350	3·5
Alloy T30K4	220	150	2
Alloy T60K6	150	100	1·5
Alloy VK8	150	210	3
Graphite EG2	150	100	2·5

If the maximum permitted regime is exceeded a toughened layer of lower quality is obtained.

The quality of the toughened layer depends in large measure on the initial composition of the surface of the article. Any appreciable roughness or the presence of corrosion, dirt, etc., on the surface markedly reduces the useful properties of the surface layer. Therefore the preparation of the surface before toughening should ensure a finish not lower than Class 5 or 6 of GOST 2789-45, and complete removal of all traces of dirt. The Sverdlovsk tool works recommend dusting the surface with a powdered flux before treatment (95 per cent colophony, 3 per cent potato starch, and 2 per cent potassium nitrate). Use of such a flux gives increased wear resistance and better surface finish. In this case very fine regimes of working are adopted: potential 24 v, capacity 51-20 mfd, current 0·6-10 amp.

The quality of the toughened layer is largely determined by the duration of the process. With prolonged treatment of one part of the surface single dark spots begin to appear, indicating incipient breakdown of the toughened layer. The precise moment of completion of the toughening is usually determined by the outward appearance of the spark which gradually loses its brilliance and form after a certain time, and this is followed by the appearance of the defective spots.

It was shown from the experiments of Cand. Techn. Sci. E. Ya. Ulitski that the quality of the toughening process is linearly related to the mechanical parameters connected with the frequency and amplitude of the oscillating vibrator. Actually the charging of the condenser takes place only with the electrodes clear or disconnected. With the hand method, using an electromagnetic vibrator and a constant frequency of oscillation of the electrode of 100 c/s, the oscillation amplitude of the toughening electrode will be varied in relation to the force applied to the handle of the vibrator. Changes in the amplitude of oscillation result in corresponding changes of time of charging the condenser, and therefore the voltage of the initial discharge. This latter, as is shown by oscillograph record, ranges from 15 to 80 per cent of the applied voltage. The different results in respect to increased life of tool after toughening are explained by the fluctuation in voltage of the initial discharge. The coefficient of increase of life usually ranges from 1·5—3·5.

A tool is made from high-speed cutting and carbon steels and subjected to electro-spark toughening when intended for working or machining hard cast-iron, carbon and special steels of high temporary resistance or ductility, e.g., such as steels RF-1, RO, 18KhNMA, ShKh15, austenitic steels, etc. In dealing with these materials the life of the toughened tool is actually increased from two to three-and-a-half times. A considerable extension of life is also observed in toughened tools used in intermittent machining of components (planing, slotting tools, dies). A tool working at high speeds and small chip section on soft constructural steels or on finish machining is not usually strengthened as this does not cause an appreciable lengthening of life.

After toughening a tool should be finally ground and finished, and should be re-toughened after each grinding. Those surfaces of the tool exposed to greatest wear should be treated and in carrying out the process it is especially important to ensure that the cutting edge of the tool is not touched or affected by the discharges. Everything possible is done to avoid the closing of the strengthening electrode with the cutting edge of the tool. Working is begun with the central part of the surface to be treated, proceeding gradually towards the cutting edge.

In the toughening of such tools as fine saws or slot milling cutters it is possible to temper the edge. In such cases it is recommended that the working regime be lowered to 20-60 mfd, with a voltage of 50-60 v and current strength 0·5 to 1 amp, and even to start working with a fine regime: 30-40 v, 10-15 mfd, and 0·25-0·4 amp. Tools requiring great accuracy of form and dimension, and high precision measuring instruments such as gauges, checking devices, jaws of slide gauges, thickness gauges, etc., are toughened by graphite treatment. A measuring instrument with a wide margin of tolerance is preferably treated with hard metal electrodes of T15K6, T30K4 (and in some cases also VK8), and subsequent finishing with abrasive laps. The working regime, selected in relation to the required surface finish, is preferably fine. The measuring surface is subjected to treatment.

In toughening band and disc saws the rear part of the saw teeth is to be treated To avoid risk of tempering (or annealing) this should be done with a medium regime in conformity with the precautions already indicated. In Table 26 are given the regimes recommended for toughening cutting tools, measuring instruments, and dies.

In recent years several industrial establishments have introduced electro-spark

TABLE 26

Tool or instrument	Part for treatment	Material of strengthening electrode	Voltage v	Capacity mfd	Current amp
Roughing tool	Front surface	T15K6	100–150	100–200	1–2
Finishing and shaping tool	Front surface	Graphite EG2	70–100	20–60	1–2
Drill	Rear surface and (lentochk) "band"	T15K6	80–120	60–150	0·8–2
Rough milling cutter ..	Rear surface	,,	80–150	100–200	1–2
Tools with ground profile:					
Form milling	Front surface	,,	75–100	20–60	0·5–1·5
Broach milling[1] ..	Rear surface	Graphite T15K6	75–100	20–60	0·5–1·5
Slot-cutter	Front surface	Graphite T15K6	75–100	20–60	0·5–1·5
Thread milling	Front surface	,,	75–100	20–60	0·5–1·5
Cutters and milling cutters for machining heat-resistant steels ..	Front and rear surfaces	,,	75–100	70–100	0·5–1·5
Cutting off saws ..	Front and rear surfaces	,,	100–150	100–150	1–2
Wood saws	Rear and side surfaces	,,	100–110	120–210	1·5–2
Dies for cold stamping ..	Working surface	,,	90–110	120–150	1–2
Chisels, point tools ..	Working surface	,,	90–100	120–210	1–2
Tips or points of pneumatic drills[2] ..	Working surface	T15K6 or VK8	110–120	180–210	2–3
Rock drills[2]	Working surface	T15K6	110–120	180–210	2–3
Precision measuring instruments	Measuring surface	Graphite	80	30	0·6
Ditto with wide tolerances	Measuring surface	T15K6 or VK8	110	up to 210	2·0

[1] Sizing teeth are not treated.
[2] After strengthening it is necessary to temper, anneal, and thereafter again strengthen.

toughening to increase the wear resistance of parts of machines subjected to abrasion or grinding. In cases where little evolution of heat is observed in the functioning of these parts their increased wear resistance after toughening (hardening, etc.) is quite appreciable.

As tools and machine components operate under widely differing conditions it would be incorrect to suggest regimes for toughening tools which are the same as those adopted for machine parts. The systems recommended by the ENIMS[1] for treating various constructional materials are shown in Table 27.

TABLE 27

Machine part material	Electrical parameters			Toughening electrode material	Remarks
	Volts	Mfd	Amp		
Steel 45	220	200–300	3	VK8	Thickness of hardened layer 0·15 mm
	110	250–300	3	VK8	
	220	500	8	VK8	
Steel 40Kh, raw, and tempered to RC 48–50	220	200	3	T15K6 and VK8	
Steel 20Kh, raw, cemented and tempered to RC 58–60	220	200	4	VK8	
	200	150	2	Sormite No. 2	
Steel ShKh15, raw, and tempered to RC 58–60 ..	220	200	3	VK8 and T15K6	
Grey cast iron SCh32	220	150–200	2–3	VK8, T15K6 and Sormite No. 2	
Modified cast iron ..	220	150–200	2–3	T15K6	
Steel 45	220	350–400	3–4	VK8	Transition regimes in two-stage working, giving a surface finish H_{mean} 1–1·5 microns
Steel 45	50	50	0·5	VK8	

According to data of the VNII MM (All Union Scientific Research Institute, Ministry of Materials) tools and components should be strengthened in the following order of operations:

1. Clean item to be treated free from dirt and rub with dry waste.
2. If necessary begin with cleaning any oxidized part of the article in order to create good contact between article and holder.
3. Mount the article in holder.
4. Fasten a strip of hard metal in vibrator clamp.[2]
5. Check that electrical connections are tight: negative terminal of unit, terminal of clamping device, positive terminal of panel, vibrator terminal, article fastenings.[2]
6. With d.c. check polarity; hard metal should be the anode.[2]

[1] Eksperimental'nyi Nauchno-Issledovatel'skii Institut. Metallorezhushchikh Stankov (Experimental Scientific Research Institute for Metal-cutting Lathes).
[2] Check and carry out only before commencing the work.

7. Check total resistance of the working circuits; it should not exceed 0·01 ohm (resistance values should be checked at least once a month); with increase in resistance it is necessary to reduce the intermediate resistance of contacts by trimming, tinning or tightening.
8. Establish the required working regime.
9. Switch on d.c. supply.
10. Turn on the main switch applying voltage to the discharge circuit.
11. Switch on vibrator.
12. Manipulating the vibrator by hand to introduce hard metal attached to it into contact with article to be treated.
13. Lead the hard metal along the part to be toughened, at first lengthwise, and then across until nature of sparking changes.[1]
14. After completion of the work, switch off the main switch and discharge capacity in contact with strip held in vibrator for working component.
15. Unfix and remove the toughened component.

Guiding economical and technical factors in electro-spark strengthening, according to data of Cand. Techn. Sci. E. Ya. Ulitski, are evaluated as follows:

Cost of plant for economical working	1000-3000 roubles[2]
Power required	0·8 to 1·2 kW
Grade of worker	3rd or 4th class
Duration of toughening process per 1 cm^2 surface	0·5 to 3 min. according to regime
Duration of toughening of one cutting tool per treated area of 15 mm^2	5—3 sec.
Consumption of electric power per 1000 tools of section 16 by 25 mm	1·2 to 1·5 kW/h
Consumption of hard metal T15K6 per one tool	2—5 mg
Increase in life of tools	Up to 350 per cent according to conditions of use.

[1] With a tool it is essential to avoid contact of hard metal with the cutting edge.
[2] 11 roubles equivalent to £1 approx.

CHAPTER III

Equipment for the Electro-spark Working of Metals

CLASSIFICATION OF MACHINES AND BASIC CONSTRUCTIONAL ELEMENTS

All electro-spark plants, according to the method of closing the discharge circuit line, are divisible into two groups: (1) non-contact and (2) contact. In contact machines the tool fastened to the spindle periodically contacts the workpiece (article). The amplitude of oscillation is usually small and amounts to 0·5 to 2 mm. Vibratory movement is generally imparted to the tool by electro-magnetic mechanism, and in some cases by eccentric or crankshaft mechanism driven by an electric motor. In machines of the non-contact type the tool is not directly in contact with the workpiece, but is at a specified distance required for normal working of the process. Existing machines of the contact type are less efficient than those of the non-contact kind, and are used chiefly for toughening, engraving, and broaching of small holes.

The basic units of electro-spark machines comprise: the frame, mechanism for moving parts, working tank, pump elements, electric impulse generator, and feed control. The frame is the connecting link or support for the other units, and is either cast or welded. The mechanism for moving parts such as tool and workpiece is in most cases much the same as in metal-cutting machines and comprises an under-carriage moving along a straight edge or guide surface by means of screw or gearing elements (couples). The working tank comprises an all-welded construction of thin sheet steel with bottom of thicker sheet. To the bottom of the tank strips of Textolite are fastened on which the worktable is placed and which insulates the tank from the table when the apparatus carries a voltage.

A connector is attached to the side wall of the tank for connecting the electrodes to the discharge circuit. One terminal of the connector connects through a busbar with the table, and the other by means of a flex to tool holder. Working fluid is fed from the pump unit through a supply nozzle in the top part of the tank, with overflow pipe near it to limit liquid in the tank to the permitted level. The working liquid is discharged through an outlet nozzle situated on a level with the bottom of tank. Dimensions of the tank are determined by the size of the articles to be treated and also by the fact that the working liquid in the tank is supplied on the basis of not less than 1·5 to 2 litres/0·2 kW of operating power of machine. Otherwise overheating may occur and ignite the working fluid.

The pumping unit is designed in the form of a tank of 50-60 litres capacity, in the upper part of which is fixed a standard electric pump supported by an angle bracket and delivering 16-20 litres/min. An opening is provided in the cover of the tank for a flexible hose by which the overflow from the other tank returns. A screen is provided to assist particles to settle out. There are holes in the bottom of the tank closed with stoppers for removing spent liquid and sludge.

Impulse generator. As already pointed out, in order to obtain discharges an arrangement is used comprising a source of direct current, a control charging resistance, condenser bank, control indicators, and working electrodes. Motor generators (series PN of the Elektrosila works, KhEMZ,[1] YaRMZ[2] and others), selenium, mechanical, and valve rectifiers, are widely used as current supply for electro-spark machines. The power of the supply is determined by that required by the coarsest regime.

Resistances in electro-spark machines consist of nichrome or constantan spirals wound in sections on ceramic cores. The value of the resistance of each section is determined from the short-circuit current of the specified regime: $R=\frac{U}{I_{sh\,c}}$ where R is resistance in ohms, U is potential of applied voltage in volts, and $I_{sh\,c}$ is the short circuit current in amp. The sections of the charging resistance may be switched in singly or in series. It should be noted that the latter method permits a reduction in the amount of wire needed for the windings.

The most suitable condenser units of electro-spark machines are of the non-inductive type. Condensers Mark MKV or KBG are the most widely used, but it is possible to use also condensers BP. The safe working voltage of the condensers should be somewhat higher than the maximum supply voltage. Capacity is shown in definite relation to the charging current strength. In most machines for toughening work a block system of controls is used permitting simultaneous switching of capacity and its corresponding resistance by means of one switch only. Operation of the machine is checked with the aid of appropriate measuring instruments.

In addition a hotwire ammeter may be included in the discharge circuit in order to facilitate adjustment of the machine to its optimum regime. In the absence of such a hotwire ammeter it is possible to substitute an ordinary electro-magnetic ammeter with current transformer. Usually the electrical equipment is housed in a separate cabinet or control panel, on which are the measuring control instruments, switches for the regimes, and other control elements.

ELECTRO-SPARK MACHINES FOR MOUNTING ON ORDINARY MACHINE TOOLS

Fundamentally existing electro-spark machines may be divided into two categories:

(1) the special type which usually consists of a compact assembly of all the required parts;

(2) machines mounted on existing metal-cutting machines and using their mechanical fittings. Compared with (1) these latter have several disadvantages—they occupy more room and are less convenient to operate. On the other hand they do offer the advantage of relatively low cost and possibly quicker assembly and operating times. Drilling and milling machines are among the most suitable for adapting to electro-spark working, since it is possible to co-ordinate table movement particularly in the latter machines.

Machines equipped for electro-spark working should be provided with (a) control panel; (b) tank; (c) pump unit; (d) feed control. The main features of an electro-spark broaching-copying machine mounted on a milling or drilling machine are given below:

[1] Khar'kovskii Elektromekhanicheskii Zavod (Kharkov Electromechanical Plant).

[2] Yaroslavskii Elektromashinostroitel'nyi Zavod (Yaroslav Electrical Machine Building Plant).

1. Dimensions of table in mm	according to the machine used
2. Maximum distance of spindle face (end) to working table, in mm	
3. Dimensions of workpiece, in mm	
4. Maximum weight of workpiece in kg	
5. Voltage of feed system	220—380 v
6. Total power requirements	4·8 kW
7. Overall dimensions of machine	1600×1700×2245 mm
8. Weight of machine	800—950 kg

Machines are provided with solenoid control type 1-5 of OKB MM design with the following technical features:

1. Maximum traverse of spindle	200 mm
2. Number of windings of electro-magnetic feed	3
3. Series winding: continuous permitted current	20 amp
4. Shunt-winding: (a) voltage	220 v
(b) resistance	400 ohm
(c) continuous permitted current	0·6 amp
5. Compensating circuit windings	
(a) voltage	36 v
(b) resistance	24 ohm
(c) continuous permitted current	1·5 amp
6. Overall dimensions	163×165×795 mm

The control is an electro-magnetic device comprising a coil with three windings placed between two supports or angle brackets attached to the main panel. Alignment of the central or core spindle is secured by ball-bearings arranged in the brackets. The spindle has a tapered opening to take the tool or chuck, the taper being insulated from the rest of the spindle by a "Textolite" lining. A counterweight or compensating system is arranged in the upper part of the unit to balance the weight of the tool if this is greater than 0·5 kg. With a lighter tool the counterweights are removed and the weight of the spindle is balanced by pull of the windings alone. One of the windings of the coil (shunt) is connected in parallel with the charging resistance, and the other (series) in series therewith. Such winding connection maintains an approximately constant pull on the spindle independently of the working regime. The third winding—the balancing or compensatory winding—is connected to the terminal of an independent d.c. source. A rheostat connected in series with this compensation winding controls the strength of the current therein. It permits variation of the pull on the spindle, and thus establishes the optimum gap between electrodes.

In this same unit a neon lamp is connected in parallel with the shunt windings, and from the nature of its lighting the operator can judge the working stability of the unit. For example, with normal working the light from the lamp pulsates uniformly, but with short-circuiting of the electrodes the light no longer pulsates and the lamp burns uniformly. Such unsteady working is also accompanied by individual flashes. This spindle unit type of construction is that used with control panel type PUE-55.

Technical characteristics of panel PUE-55 are as follows:

1. Power supply	3·3 kW
2. Potential of a.c. supply	220-380 v
3. Rectified potential	220 v
4. Type of rectifier	Selenium

5. Short-circuit current with 220 v		
	(a) maximum	25 amp
	(b) minimum	0·5 amp
6. Capacity—	(a) maximum	386 mfd
	(b) minimum	2 mfd
7. Number of switches of regime control		7
8. Number of working regimes		219
9. Overall dimensions		570×690×1220 mm
10. Weight		300 kg.

When the main switch is closed alternating current from the 220-380 v supply passes to the transformer which, in addition to primary and secondary windings, has three auxiliary secondaries. From the first of these secondaries a voltage of 36 v is applied to the selenium rectifier of the compensating (balancing) circuit; from the second auxiliary it is fed to the plug socket intended for feeding the vibrator coils in cases where the panel is used as a toughening unit; the third auxiliary winding feeds the signal lamp in the panel and the fan used for cooling the charging resistance. From the mains secondary a voltage of 220 v passes to the selenium rectifier connected according to the 3-phase arrangement of Larionov. On closing the switch rectified voltage is fed through a contactor to the circuit which comprises six condenser blocks connected in series with resistances. These blocks are connected with the spark gap, i.e., establishing the working regime, through the switches (knife or cut-out switches).

In order to avoid burning the contacts of these switches at the moment of switching, contact pieces are suitably arranged under their poles, disconnecting the d.c. In the d.c. circuit a relay is inserted to protect the selenium rectifier from overload. This relay operates with a mean working current above 15 amp, and disconnects the contactor circuit of the d.c. When the unit is to be used for hardening or toughening and requires small currents a switch is provided, to disconnect the resistance from the capacity in two of the condenser blocks. For controlling the pull of the balance windings on the spindle of the unit a rheostat is provided. Control of pull in the shunt and series windings is effected automatically by variation of the charging current. In this case the joint action of the windings ensures maintenance of the necessary pull on the spindle independently of the strength of the charging current. This, in turn, permits steady working of the unit throughout the whole range—from the very fine to the very coarse regime. With an increase in strength of the charging current and a voltage drop on the selenium rectifier, there is also a voltage drop on the shunt winding, as a result of which the ampere-turns of the shunt windings are reduced. However, increase in current strength in the series windings also causes an increase in its ampere-turns and thus balances a lowered pulling force of the shunt winding. In this way the total pull applied to the spindle by both windings remains nearly constant.

All the elements of the electric circuit-resistances, capacities, rectifier with transformer, control panel, and balancing circuit rheostat, are mounted in a specially shaped metal cabinet. Terminals, etc., for connecting up the machine are placed on the side of the panel and covered with wooden casing to exclude the possible risk of contact with the live part. When necessary the lower part of the rear cabinet wall is removed to give access to the starting and protective apparatus. The panel with the measuring controls, switches for changing regimes, button switches, and commutator units, is located in the upper part of the assembly. The hand control of the balancing circuit rheostat is mounted on the front part of the panel.

Resistances are mounted on the frame in the upper part of the assembly. A fan is fixed below for cooling these resistances. The condensers grouped in two boxes are situated in the middle part. The rectifier with transformer is mounted in the lower part. Near the rear of the rectifier the fuses, a thermal relay, magnetic starter for the d.c., main lead switch, and terminal for connecting panel to supply are placed on a "Textolite" panel.

SPECIAL ELECTRO-SPARK MACHINES

Bench electro-spark machine type EISN-03 (of OKB MM design.) This is intended for small broaching, copying, and engraving work. Its technical characteristics are as follows:

1. Working area of table		120×200 mm
2. Traverse of table		
	(a) longitudinal	100 mm
	(b) transverse	60 mm
3. Displacement of spindle head (unit)		250 mm
4. Automatic traverse of spindle		70 mm
5. Range of regimes—		
	(a) maximum	220 v, 62 mfd, 3 amp
	(b) minimum	36 v, 0·25 mfd, 50 m/amp
6. Maximum capacity (for steel)		100 mm³/min
7. Maximum power requirements		0·8 kW
8. Overall dimensions of machine		450× 340 × 600 mm
9. Overall dimensions of panel (desk)		350 × 540 × 410 mm
10. Weight		95 kg

The machine comprises two independently constructed units—the machine itself and the control panel. The former consists of a supporting frame which carries the tank containing the working table and a column with spindle head moving along it. Movements of the working table and spindle head are adjusted as necessary by hand with the aid of screw and gearing trains. A small container for the working fluid is connected with the tank by rubber tubing. The tank is filled and emptied by raising and lowering the container. The construction of the spindle head differs little from that of the G-5 type, except in that the machine now described the coil of the electro-magnet has two windings: balancing and basic. The latter is connected up with the charging circuit, either in parallel or in series according to the working regime used. In working with fine regimes the head or unit is provided with magnetic control in order to increase the pull of the electro-magnet.

The electrical part of the machine is fitted into a control panel in the form of a desk type cabinet with plastic facings. A valve rectifier consisting of two gas rectifiers VG-236 is on the rear wall of the desk. In order to obtain direct current of varying voltage a transformer is inserted across the rectifier. With the aid of change-over switch voltages of 40, 85, 132, 180 and 250 may be taken from the transformer secondary. Variation in the strength of the charging current is obtained with the change-over switch. The group of eight condensers of different capacity is switched in by means of link condensers. The basic winding of the electro-magnet is connected in parallel or in series to the charging circuit by means of a change-over switch. When in parallel the current in the windings is controlled by rheostat. The balancing winding is fed through an auxiliary circuit comprising a selenium rectifier and rheostat varying the current in the balancing circuit. Direct current is supplied through a switch. All the machine controls (main switch, connectors, voltage change-over switches, etc.) and also the measuring control instruments are mounted on the front panel of the desk. The connections to an a.c. supply and to the machine are placed on the rear wall of the desk panel.

Machine with vibrating table, Type LV-14[1]. This machine is intended for producing holes of 0·1 to 0·35 mm diameter in small components. The electrical part is mounted in a cabinet forming the base of the machine. Hand controls and measuring instruments are carried on the front and side walls of the cabinet. This machine belongs to a group of the contact type. Periodical contact of the electrodes is produced by the vibrating table to which is attached the workpiece, and vibratory movement is imparted to the table by an electro-magnetic vibrator mounted on the main column of the machine. The pole pieces of the vibrator are placed at a distance of 0·5 to 0·6 mm from the armature which is rigidly attached to the table.

In changing workpieces the table is lowered or turned about one of its supports. In cases where the workpiece is displaced laterally from the axis of symmetry of the table it is balanced by a weight fixed in the appropriate position. A sleeve or bush is located in the middle part of the vibrating unit which acts as a slide guide for the tool. The sleeve is of brass and has two inserts (bearings) of porcelain or glass. The amount of clearance between wire tool and walls of guide sleeve is 0·005 mm. The wire tool is fed into the groove of the sleeve through two ebonite rollers, one of which is pressed towards the other by a special spring until they contact. Since the rollers are connected together by toothed gearing there is no possibility of wire slipping, and the feed into the groove of the sleeve is sufficiently uniform.

The tank for the working liquid can be moved along the column of the machine and fixed in any desired position. The workpiece is immersed by raising the tank to the desired height. In order that the wire tool shall have the required straightness the machine is fitted with a straightening device. This and the coil for the wire tool are placed on the upper end of the column. Accuracy of working with this machine is high (Table 28); although operating within the prescribed tolerance limits is only possible in the absence of sharp voltage changes in the supply system. It is therefore necessary that the supply be obtained from a separate motor generator or through a voltage stabilizer.

TABLE 28

Diameter of hole mm	Depth of hole mm	Prescribed diameter tolerance mm
0·152	0·7	+0·008
0·35	2·5	+0·015

[1] Leningrad Lesotekhnicheskoi Akademii im. S.M. Kirova. (Designed by the Leningrad S.M. Kirov Timber Technical Academy.)

The technological data of the machine are given in Table 29.

TABLE 29

No.	Technological parameters	For holes 0·152 + 0·008 mm	For holes 0·35 + 0·015 mm
1	Feed (applied) voltage	105 v	80 v
2	Mean value of voltage in the discharge circuit	50–70 v	40–50 v
3	Strength of short-circuiting current	0·05 amp	0·8 amp
4	Mean value of current in charging circuit	0·3–0·35 amp	0·3–0·4 amp
5	Capacity of condensers	0·25 mfd	1·1 mfd
6	Strength of current in vibrator	35 m/amp	50 m/amp
7	Amplitude of vibration	0·24 mm	0·2 mm
8	Depth of hole	0·7 mm	2·5 mm
9	Diameter of wire	0·11 mm	0·31 mm
10	Wire electrode mark	LS59	LS59
11	Duration of broaching of one hole 1·5–2 mm deep	18–20 sec	1·5 min

Electro-spark machine type LV-15. (Designed by the Leningrad S.M. Kirov Timber Technical Academy.) The machine is fitted with a motor regulator and belongs to the automatic non-contact action group. The machine is intended for accurate operation in the production of working contours or profiles of small shearing or punching dies and trimming dies for drop forgings, holes in drawplates for wires, etc. The technical characteristics are as follows:

1.	Working area of table	100 × 150 mm
2.	Table traverse (longitudinal)	120 mm
3.	Tool head traverse (transverse)	100 mm
4.	Automatic shift of tool carriage	200 mm
5.	Maximum depth of broaching under pressure	75 mm
6.	Maximum dimensions of workpiece	200 × 150 × 60
7.	Maximum weight of workpiece	20 kg
8.	Short-circuiting current with 220 v	0·1 – 15 amp
9.	Nominal current	8 amp
10.	Capacity of condenser	0·25 – 128·75 mfd
11.	Type of rectifier	Selenium
12.	a.c. voltage	220 v
13.	Rectified voltage under nominal load	220 v
14.	Control system	Automatic regulator with contrary magnetic fields.
15.	Cooling unit for resistances and rectifier	Enforced air
16.	Dimensions of machine	570 × 460 × 1000 mm

The electrical system of the machine is of the usual type. A built-in selenium rectifier connected directly with the a.c. mains of industrial frequency serves as current source. The condenser group is divided into five parts comprising condensers of the non-inductive type connected in series with the resistances. The central points of the condenser system are connected through plug-in or connecting links with the working electrode. By means of the different connections of these four links a wide range of regimes is possible. The "finest" working regime is established with the connector links unplugged, giving a constant capacity of 0·25 mfd, constant resistance of 2000 ohms, and the resistance in one of the pairs of windings of the follower or control system.

The machine is supported on a specially designed box structure faced with sheet metal. The lower part of the machine forming the base of the frame houses the ventilator unit, the feed control or double magnetic clutch, and the mechanism for raising and lowering the tank. The resistance block is in the upper part; the ballast resistances are in the form of spirals wound on porcelain cores; and the condenser unit and the selenium rectifier are beneath the resistance block.

The condenser unit is made as a sub-assembly. Condensers of the non-inductive type are connected in blocks of specified capacity. To facilitate the mounting of the condenser unit the block of resistances and the selenium rectifier are fitted on a common base which slides into the upper part of the apparatus.

On the right-hand side of the main body are the switches for connecting up the machine and the motor of the regulator, handle of the sliding contact of the variable resistance of the regulator circuit, and switches of the connector link type for the different regimes. On the front of the main body of the machine are the instrument panel, with measuring instruments and guide grooves or edges for the tool carriage, and the table carrying the workpiece. On the tool carriage is the movable slide rest to which the tool is fastened.

The working table is placed on a suitable base under the cantilevered or bracketed table. The workpiece is immersed in the liquid by raising the table with the aid of mechanism actuated by turning the handle. On the left-hand side of the machine frame are the terminals for connecting up with the a.c. mains.

Tool feed control includes:

(1) tool rest of the bracket type movable along the guide grooves or edges of the frame by means of lead screw connected by a sleeve with the drum of an electro-magnetic friction clutch;

(2) electro-magnetic friction clutch, the shaft of which is actuated through worm gear from the shaft of the twin magnetic clutch;

(3) the actual or main drive, namely, the twin electro-magnetic clutch driven through a reduction gear by an a.c. motor.

The control unit operates as follows. With an electric current flowing in either of the windings of the twin electro-magnetic clutch the magnetic field formed attracts the armature towards the energized pole pieces. The pole pieces of both windings are rotated by a motor through bevel gear transmission, and therefore each system rotates in opposite directions. The direction of rotation of the spindle depends on the direction in which the armature is pulled, since the armature is connected with the shaft through a square spline. The direction of rotation of the driving shaft and of the mechanism transmitting movement to the tool-holder are so selected that when the armature engages with the upper energized pole of the system the tool approaches the workpiece; and conversely, when the armature engages with the lower pole-piece the tool moves away from the workpiece.

The pole-piece windings are connected in circuit so that the fields established thereby are mutually opposite. In the absence of a discharge between tool and workpiece no voltage drop is observable in the charging resistance; the armature is attracted to the upper system of pole-pieces thus causing the electrodes to move together. When the electrodes approach each other closely enough to cause discharge the voltage drop in the charging resistance is associated with current flow in the basic windings of the lower system of pole pieces, so that it will tend to attract the armature to itself and pull it away from the upper. This tendency will also be strengthened by the demagnetizing effect of the auxiliary windings of the upper system.

With a definite voltage drop on the charging resistance the action of the magnetic poles will be mutually balanced; the armature will be stationary, and feed of tool will cease. In the event of a further voltage drop on the charging resistance the force of attraction of the lower pole-pieces will be greater than that of the upper and the armature will be attracted towards it. In this case the direction of rotation of the armature is reversed, and the tool will move away from the workpiece until the influences of the magnetic fields are again balanced.

Besides the twin electro-magnetic clutch there is also a frictional electro-magnetic clutch in the kinetic system of the regulator. When the machine is operating the windings of this clutch are exposed to the full supply voltage, and the magnetic field created thereby ensures safe and reliable engagement of disc and sleeve, thus transmitting movement to the lead screw. With no current in the winding the coupling of disc and sleeve is released and the lead screw is disconnected from the drive mechanism. Transmission to the lead screw in this case is effected by a manual gear drive, permitting a more rapid adjustment of the tool rest. This is necessary for feeding the tool into the starting position and its removal on completing the work.

Electro-spark machine of the Krasnogvardeets factory, type EISK-3. This machine (Fig. 19) is designed for broaching-copying work.

The technical characteristics are as follows:

1.	Overall dimensions of table	300 × 540 mm
2.	Vertical displacement of head	400 mm
3.	Automatic traverse of spindle	60 mm
4.	Type of tank	Lifting
5.	Volume of tank	60 litres
6.	Voltage of feed source	220 v
7.	Maximum capacity	500 mfd
8.	Minimum capacity	2 mfd
9.	Maximum short-circuit current	60 amp
10.	Minimum short-circuit current	0·4 amp
11.	Maximum capacity	330 mm^3/min
12.	Power required	10 kW
13.	Overall dimensions of machine	1000 × 1050 × 1780 mm
14.	Weight	700 kg

The electrical system of this machine differs from those previously described only in that it does not include a d.c. source. Supply is obtained from a motor-generator of 10-12 kW. The condenser unit of the machine has seven groups of condensers connected in series with the resistances as follows.

Group No.	Capacity mfd	Limit resistance ohms	Erosion of metal mm³/min
	(Material worked is steel)		
1	2	550	3·21
2	6	220	6·28
3	12	110	12·55
4	48	30	37·0
5	96	22	64·6
6–7	168	11	117

By suitable combination of connecting links the seven groups of the condenser unit of the machine can give fifty-seven different output regimes. The finest regime is obtained with parallel linkage of all seven groups.

The machine (Fig. 19) has a cast-iron sheet or plate frame support with table to take the workpiece. Tool feed regulator is electro-dynamic head 2 on a special angle-bracket 21 above the table and capable of movement in the three co-

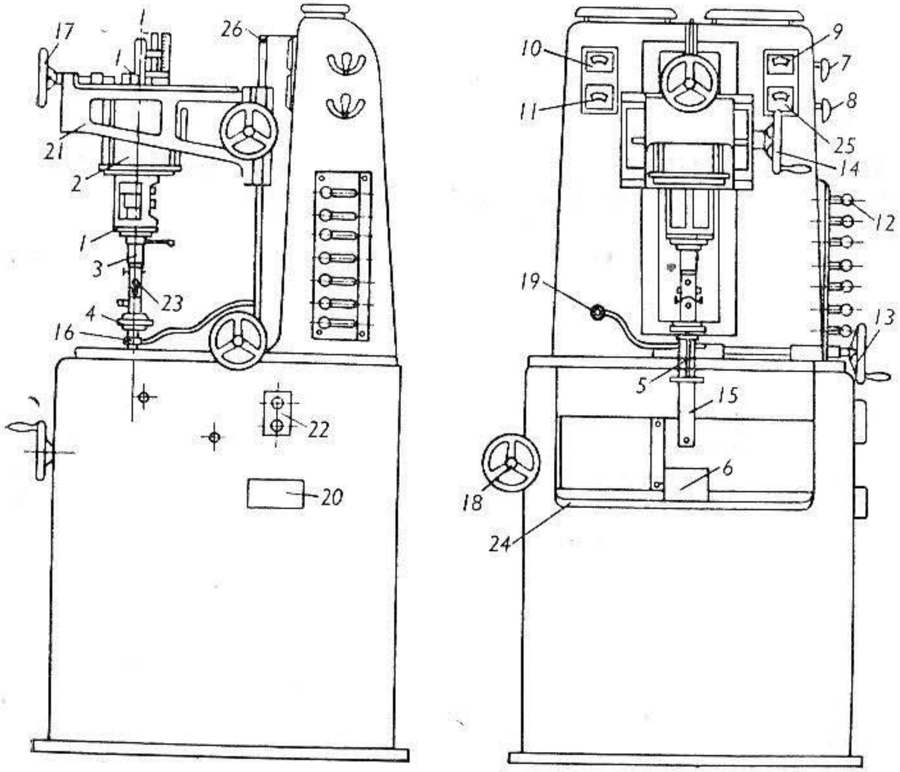

Fig. 19. Machine of the Krasnogvardeets factory

ordinates. At the front of the upper part of the machine is the guide rod 26, of the bracket carrying the electro-magnetic head, with screw 22, between these giving preliminary adjustment of height of head. Movement of the head along the front of the machine and perpendicular to it is controlled by hand-wheels 14 and 17.

Two voltmeters are mounted to the left of the guide: the upper 10, for measuring voltage of charging circuit, and the lower 11, for measuring that of the discharge. To the right are two ammeters: the upper 9, for measuring the current when working with fine regimes (0 to 5 amp), and the lower 25, for measuring current for coarser regimes (0 to 100 amp). Lower down is a terminal (—) 19 for connecting the tool 5; and the second terminal (+) 15 is for the lead to the workpiece or article 6 through a busbar, measuring 4 × 10 mm. On the top right-hand side of the machine two handles 7 and 8, adjust the follower or control system; and below these are seven knife switches or cut-outs, 12, for switching in the required capacity and resistance. Here the top switch corresponds to the finest regime.

The lower part of the frame is divided into front and rear sections. The front section holds the welded steel tank 24, balanced by counterweight. The tank is raised by means of pilot wheel 18, to the position in which the stationary table of the machine together with workpiece is immersed in the working fluid poured into the tank, or freed from liquid when the tank is lowered. In the rear section are the condensers, the block of resistances, and the magnetic starter, the "start" "stop" buttons of which are on the side of the frame. Below the starter buttons are terminals 20 for connecting the machine to the d.c. source.

The head of the automatic tool feed control unit has a cylindrical body in which are mounted the electro-magnetic unit and guide rail for displacement of spindle 1 which is supported in a system of ball bearings. The head spindle is designed in the form of a steel tube on which are mounted two coils interacting with a fixed coil attached to the main body of the head.

The chuck or socket for holding the tool is placed in the lower part of the spindle. This has a "Textolite" washer 4 which insulates it from the rest of the spindle unit. In addition the spindle is provided with a hinge or joint 23 for use when the tool is to be adapted for copying work.

Bench machine for the production of chip-breaker grooves[1] The machine is intended for producing chip-breaking grooves on lathe tools and other forms of tool.

The technical characteristics of the machine are as follows:

1.	Power required	0·3 kW
2.	Voltage of mains a.c. supply	220-380 v
3.	Voltage applied to electrodes (idle running)	140 v
4.	Short-circuit current strength	4 amp
5.	Capacity used	20 mfd
6.	Inductance in the charging circuit	0·05—0·1 henry
7.	Spindle traverse	3 mm
8.	Weight of the machine	47 kg
9.	Dimensions	436 × 390 × 472 mm

The usual condenser arrangement is used in conjunction with inductance in the charging circuit, the electro-magnet of the feed regulator being used as the

[1] Constructed by OKB MM.

inductance. All the units and electric equipment are mounted in a light welded frame serving as the base of the machine. The working tank is mounted in the lower part, on a rack or shelf. Over this mechanism is fastened a rocking lever for holding the workpiece, and the tool feed control. The tool with workpiece is immersed in the tank by hand pressure on the head of the feed control. When the workpiece is immersed in the tank, i.e., on pulling the lever down to the lower position, the switch is closed and voltage is applied to the magnetic starter, to the discharge circuit, and to the time relay. The relay governs the time cycle for the operation and, after the specified time, switches off the starter, and the working operation ceases. Simultaneously with this the electro-magnet is switched on and pulls out the pin holding the lever in the lower position. The released lever springs upwards into the non-operative position, and switches or changes over the switch so that the machine is again ready to repeat the cycle of operations. For cutting tools of 25 × 16 mm the output per machine shift reaches 400 items.

Machine for extracting broken tools. This machine designed by OKB MM and based on selenium rectifier VSA-6M has the following characteristics:

1.	a.c. supply voltage	110/127/220 v
2.	Power required	1·4 kW
3.	Working voltage	24 v
4.	Short-circuit current	24-30 amp
5.	Capacity	6 mfd
6.	Automatic traverse of spindle	70 mm
7.	Maximum depth of broaching	35 mm
8.	Maximum area of broaching	8 mm²

The general arrangement and basic principles of the machine are shown in Fig. 20. The machine includes an upright support carrying a solenoid unit, a standard rectifier unit, a panel carrying the resistance capacity, and rheostat of the balancing circuit. The construction of the solenoid head is similar to that of the feed regulator of machine EISN-03. The unit is lowered and raised in the pedestal support with the aid of a pilot wheel. The head pivots about a joint in a horizontal crosspiece which permits its adjustment at an angle to the vertical plane. The unit can turn through 360° around the axis of the upright. The selected position of the head is fixed by suitable clamp or lock.

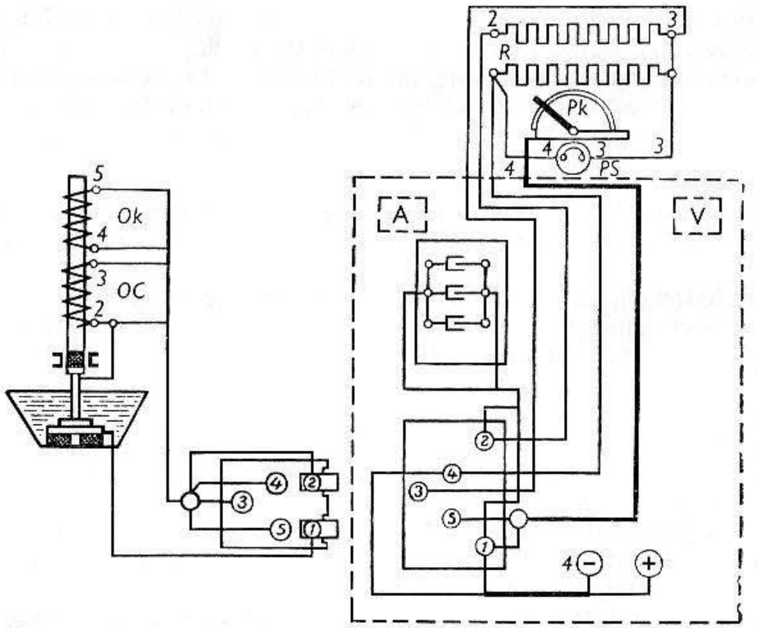

Fig. 20. Electrical arrangement of machine for extracting broken tools

PLANT FOR TOUGHENING METALS

The general arrangement of apparatus for electro-spark toughening does not differ in principle from that of machines intended for broaching work. Therefore, some of the machines already described, and others, may be used for toughening. Since, in electro-spark toughening the operation proceeds by the contact method, the control panel (desk) should be provided with a vibrator, to ensure periodical contact of the electrodes. Vibrators forming a very simple electro-magnetic system are the most frequently used. It is desirable that the vibrator should have the following characteristics:

1.	Current in vibrator coil	a.c. at 36 v
2.	Number of turns in coil	670
3.	Diameter of coil wire	0·5 mm

Apparatus for electro-spark toughening, Type PP-58[1] is intended for hardening or toughening various tools and components. Its characteristics are:

1.	Voltage of a.c. mains	120/220 v
2.	Rectified voltage	30–130 v
3.	Nominal load	0·1–4·5 amp
4.	Maximum capacity	210 mfd
5.	No. of possible capacity changes (links)	7
6.	Maximum power required	0·6 kW
7.	Dimensions	480 × 370 × 852 mm
8.	Weight	100 kg

The electrical circuit of the apparatus contains: a source of d.c., a condenser block with change-over switches, and an electro-vibrator, to the armature of which is attached the working electrode. No resistances limiting the current for charging condensers are used. This function is fulfilled by the transformer winding of the selenium rectifier VSA-3M used as source of d.c. The rectifier transformer is provided with a magnetic shunt for smooth variation of output voltage from 30 to 130 v, whereby the working regime is controlled through variation of the supply voltage.

The rectifier housing contains the selenium rod, transformer, ammeter and voltmeter, selector switches for d.c. and a.c., signal lamp, and protective armature or shield. Underneath the rectifier housing is a metal cabinet containing the condenser unit having three blocks of capacities 30, 60, and 120 mfd, which is connected by a lead to the d.c. supply from the rectifier circuit. Three selector switches for seven different capacities: 30, 60, 90, 120, 150, 180 and 210 mfd, are arranged on the front face of the cabinet. On the right hand side of the cabinet a socket is provided for the plug of the vibrator to which is applied a voltage of

[1] Constructed by OKB MM.

36 v from the terminal of the rectifier transformer. The two terminals for connecting up the workpiece (—) and the vibrator (|) are on the front wall of the cabinet. The apparatus is provided with a vibrator type V-2u.

Apparatus of the Kinap factory. Type KEI-1, belongs to the category of apparatus having fixed regime values.

The technical characteristics are as follows:

1. Power	0·3 kW
2. a.c. mains supply	220 v
3. Capacity—maximum	120 mfd
minimum	6 mfd
4. Short circuit current—maximum	1·5 amp
minimum	0·25 amp
5. Dimensions	480 × 225 × 370 mm
6. Weight	25-26 kg

In the electrical circuit of the "Kinap" machine a rectifier is used (valves VG-129). The rectifier is provided with a transformer of which the primary is fed with 220 volts a.c. mains. Besides the secondary power winding the transformer also has two auxiliary windings: one for the supply to the electro-magnetic vibrator, and one for heating the rectifier valves. The value of the rectifier voltage in the charging circuit is 150 v. The condenser unit of the apparatus has a total capacity of 120 mfd in three blocks of 6, 34, and 80 mfd. Each block is connected in series with a group of standard vitreous resistances up to 500 ohms. By suitable combinations the regimes shown in Table 30 may be obtained:

TABLE 30

No.	Regime	Capacity mfd	Current amp
1	Coarse	120	1·5
2	Intermediate	86	1·0
3	Medium	40	0·75
4	Fine	6	0·25

All circuit components (transformer, rectifier, condensers, resistances) are mounted on a cabinet faced with sheet iron. The front and rear panels form covers fastened by screws. Louvres are provided in these covers and in the floor for cooling the rectifier valves and the resistances. In recesses on the front of the apparatus are the main switch, switches for the different regimes, and the terminal for connecting up the workpieces to be toughened. On the right-hand side panel are the sockets for the vibrator lead and for a.c. main connection.

The electro-magnetic mechanism of the vibrator comprises an iron cored coil fitted with an armature, attached to a flat spring.

When current passes through the coil mechanical oscillations are produced in the armature and in the holder of the toughening electrode rigidly attached to it. The electro-magnetic mechanism is in a plastic frame to which is fastened a handle containing three leads. Two of these feed the electro-magnetic mechanism, and the third connects the vibrator to the discharge circuit of the apparatus.

Electro-spark apparatus Ionator S-2.[1] This is for toughening tools and dies. The technical characteristics are as follows:

1. Power	0·2 kW
2. a.c. mains supply	220 v
3. Capacity—maximum	60 mfd
minimum	15 mfd
4. Short circuit current—maximum	2·5 amp
minimum	0·1 amp
5. Working voltage—maximum	80-100 v
minimum	20-25 v
6. Weight	5 kg

The general arrangement of the apparatus consists of:

(a) transformer with a stepped secondary winding;
(b) selenium rectifier comprising 24 selenium discs of 45 mm diam.;
(c) condenser unit composed of six condensers of 10 mfd each;
(d) commutator and measuring instruments.

All the circuit components are contained within a metal box measuring 124 × 204 × 204 mm. On the front face of the box are mounted the measuring instruments, the main switch, four voltage change switches, and two for working regimes. Here also are the terminals for connecting the apparatus to the a.c. mains and to the vibrator. The apparatus has a vibrator of lightweight construction (150 g). The electro-magnetic mechanism of the vibrator consists of a core mounted on a rod supported by a flat spring, the core being surrounded by a coil and the whole arranged in a carbolite casing of the lampholder type. The holder of the working electrode is attached to the end of the rod by means of an intermediate "Textolite" bush.

SAFETY PRECAUTIONS IN OPERATING ELECTRO-SPARK MACHINES AND FIRE-PREVENTION METHODS

1. Only persons who have passed the minimum technical examination in electro-spark operation and in fire prevention are admitted for servicing and working electro-spark machines and apparatus.
2. Workers should perform only those industrial operations for which the machine or apparatus is intended.
3. Persons allowed to operate electro-spark machines and apparatus should know how to render first-aid to those suffering from shock.
4. In the shop containing machines and apparatus there should be a supply of drugs, etc., for first-aid in accidents.
5. There must always be at least two persons present during working hours in the shops.
6. The presence of unauthorized persons is prohibited on the premises during working hours.
7. A rubber mat must be placed on the floor in front of each switchboard, source of current feed, and machine.
8. Suitable warning notices must be placed on all machines, control desks and switchboards.
9. All equipment should be safely earthed. The quality of the earthing should be checked in accordance with the rules for the use of electrical apparatus.

[1] Designed by Inst. Orgtransmash. (Institute of the Transport Machinery Organization).

10. It is forbidden to remove from electro-spark machines and plant any screens or shields guarding the electrical apparatus.
11. It is forbidden to contact with the hands current-carrying parts of the machines and apparatus when voltage is switched on. The presence of voltage in the apparatus should be indicated by signal lamps.
12. It is forbidden to effect changes in capacity with voltage switched on.
13. Persons attending the machines should wear rubber gloves, and those attending apparatus for toughening or strengthening should have protective glasses (with light blue tint).
14. After completion of work on plant for toughening the condenser unit should be discharged by contacting the electrodes when switching off the feed circuit.
15. The workshop for electro-spark machines and apparatus should be well lighted.
16. In rooms or shops containing electro-spark machines there should be a general exhaust fan, and local or special fans for powerful machines.
17. In setting up a machine for work it is necessary to observe the following conditions:

    Adjustment of electrode-tool and workpiece is effected with voltage switched off and short-circuited condensers;

    After immersion of the electrodes in the working liquid its level above the surface of the workpiece should be not less than 60 mm in working with coarse regimes; 40 mm when working with medium regimes; and 15 mm when working with fine regimes.
18. In case of fire the first essential is to switch off the current. Extinguishing the fire in the working zone of the plant with water and foam extinguishers without first switching off from the mains source is prohibited.
19. It is forbidden to keep any stock of kerosene or oil in or near the place where the plant is located.
20. When work at the plant is finished, fuel (combustible liquid) should be emptied from the working tank into a covered container and stored in a special place.
21. It is forbidden to have any easily combustible material within five metres of the plant.
22. It is forbidden to smoke near the plant or to use blowlamps, etc.
23. It is forbidden to use paper, cardboard, or other inflammable material as a protection against splashings from the tank of the machine.
24. A special pulverulent or carbon-dioxide fire-extinguisher should be provided in the workshop.

CHAPTER IV

Practical Experience of Industrial Co-operative Societies Using Electro-spark Machining

The electro-spark method of treating metals is mostly used by various industrial groups for increasing the life of metal-working tools. Meanwhile, other electro-spark operations have not been on any appreciable scale. The introduction of electro-spark toughening took place about the beginning of 1949, and some twenty industrial associations now use this method of increasing tool life.

The electro-spark toughening of the cutting parts of a tool or die is widely used in the Leningrad industrial and professional bodies "Metalloinstrument", "Metallistkooperator", "Metalloshtamp", "Satury", "Elektroarmatura", "Krasnyinapil'nik", "Elektrooborudovanie", "Elektrotekhpribor", "Kromet", "Lenemal'er", "Shtampmetiz", "Velo". In the category of tool-toughening are included: punching dies for cold stamping or pressing, sizing dies, cutting tools, files, chisels, hacksaw blades, cutting pliers.

Only one organization, the "Krasnynapil'nik" has an industrial size plant, (of type KEI-1 of the "Kinap" works). In all the other organizations of the Lengorpromsoveta (Leningrad Municipal Administration Committee) the electro-spark outfits are made by themselves with electrical systems similar in most cases to that of the "Kinap" plant.

For example, in the "Metalloshtamp" works a plant is used with an electrical system as shown in Fig. 21 (the installation of which was done by the plant electrician). The machine has its own source of d.c. and a motor generator is used for supply, with a working voltage of 120 v, which also drives a surface grinding machine. The charging surface comprises three groups of resistances (R_1 220 ohms, R_2 120 ohms, and R_3 80 ohms) respectively, connected in series with three groups of condensers (C_1 4 mfd, C_2 40 mfd, and C_3 80 mfd). With various combinations seven different regimes can be obtained. (cf. Table 31).

TABLE 31

Regime characteristic	Number of regime						
	1	2	3	4	5	6	7
C (mfd)	4	40	44	80	84	120	124
$I_{sh\ c}$ (amp)	0·55	1·00	1·45	1·50	2·05	2·50	3·05

The electrical part of the machine is mounted in a cabinet or small rectangular cupboard measuring 35 × 40 × 70 cm. In the upper part are the three blocks of condensers of capacity 4, 40, and 80 mfd. A little below the condensers are the three sets of resistances wound with nichrome wire of 0·3 mm diameter. On the front of the cabinet are the main switch and three regime switches (four in all) of the press-button type. The top of the cabinet serves as working space for the toughening of dies and tools. The measuring instruments are absent, since, with

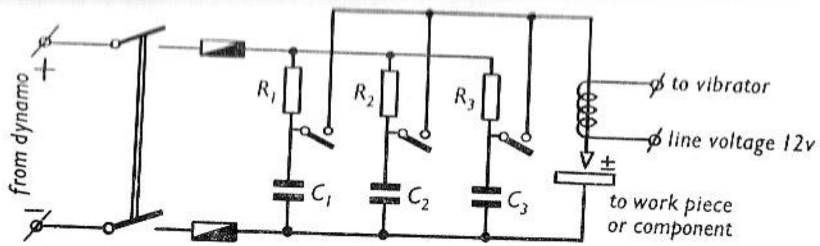

Fig. 21. Electrical arrangement for machine of the Metalloshtampartel

definitely determined values of regimes, there is no need for these. The vibrator is similar in design to that of the "Kinap" factory. However, in order to reduce weight the dimensions of the cabinet and hand control of the vibrator are somewhat less than those of industrial size. According to their data the maximum capacity obtainable with the apparatus, 124 mfd, ensures effective working only when treating dies of medium size; for larger dies capacity should be up to 200 mfd.

The Lengorpromsovet teams use apparatus other than that with fixed regimes like those described above. For example, apparatus was designed by the Primus group with separate capacities and resistances as shown in Fig. 22. (Owing to liquidation of the Primus group the apparatus has now been taken over by the Velo team). In designing the electrical system some slider rheostats that were

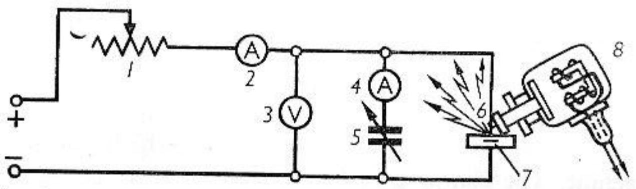

Fig. 22. Electrical system of apparatus of the Primus artel

1—Charging resistance
2—Ammeter of the charging circuit
3—Voltmeter of the charging circuit
4—ammeter of the discharging circuit
5—Condenser unit
6—Working (toughening) electrode
7—Workpiece
8—Vibrator

then available were used for the charging resistance. Since there were no fixed regimes (with control effected by selecting the corresponding values of capacity and limiting voltage) the required measuring instruments were provided in the design.

The Lengorpromsovet use hard metal (alloy) mark T15K6 as the principal material for the working electrodes in toughening tools and dies. The regime parameters, according to the form or type of tool to be dealt with, are within the following limits: voltage, 50-220 v; short-circuit current 0·25–3 amp; capacity 1·0–200 mfd. The selection of the regime suitable for any specific case depends on the experience of the operator. The working surface of the tool is previously cleaned from all traces of scale, rust or other contamination. Parts subjected to toughening are: in cutting punches—the face of the die and edge of matrix; in dies for hot stamping—projecting part of die and profile edge; face-milling cutters—the rear edges; drills—the rear face and the stem to length of 10-15 mm; or cutting tools, the front edge; and for cutting pliers, etc., the grooves or slots. t has been shown that the life of the treated tools and dies is tripled or uadrupled.

Electro-spark toughening of tools is much less used in the Mosgorpromsoveta Moscow Municipal Administrative Committee). Out of seventy metal-working roups only three have become fully familiar with this method of extending tool ife, namely:—Elektrooborudovanie, Vtoroi (2nd) and Vos'moi (8th) nechanical factories. In the first of these the apparatus used is that of the eningradskaya Lesotekhnicheskaya Akademiya obtained by the group from he Tsnilelektrom (Central Scientific Research Electrical Installation Laboraory). The electrical system of the plant is shown in Fig. 23. With the aid of this

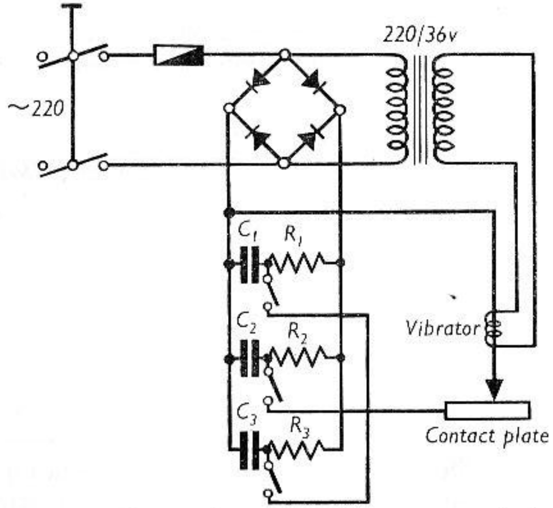

Fig. 23. Electrical system of apparatus of the Elektrooborudovanie artel

apparatus the group has succeeded in toughening, punching and bending (shaping) dies, with regimes shown in Table 32.

TABLE 32

Characteristics	No. of regime switches		
	1	2	3
Voltage (v)	220	220	220
Short-circuit current (amp)	0·5	1·0	1·5
Capacity (mfd)	30	90	180

According to statements of members of the group, by toughening the tools mentioned it was possible to obtain a two- or three-fold extension of life.

At present experimental work is in hand by the Elektrooborudovanie group with a view to constructing a more powerful apparatus for the toughening operation, also an electro-spark machine intended for the production of dies. The leader in this work is Engineer T. I. Mokeev. At the Vtoroi mechanical works an electro-spark machine of type PP-58 has been constructed by the efforts of the works staff themselves, and put into operation, under the direction of Eng. A. V. Nosov. A number of essential modifications have been introduced into this factory machine as compared with the actual machine PP-58 (Chapter III, p. 55) to improve its useful characteristics. Thus, for example, the panel attachment can be extended, and its upper surface may be used, during the toughening process, as a contact plate; a special movable combined work-bench and cabinet is provided; the selector switches are replaced by the more convenient press-button type; the press-button device switching in the vibrator coil is replaced by a single pole change-over switch, thus making the vibrator more convenient to operate.

At these works built-up compound dies for stamping out rotor and stator plates of electric motors, dies for stamping out transformer and choke cores have been subjected to the toughening process with hard alloy T15K6, using regimes listed in Table 33.

TABLE 33

Class of die	Current amp	Voltage v	Capacity mfd
Simple configuration, with clearance up to 0·04 mm	1–2	60–100	120–200
Simple configuration, with clearance 0·03 mm ..	1–2 0·5–1	60–100 80–100	80–120 20
Larger simple (plain) configuration	1–2	60–100	80
Larger complex configuratoin	0·5–1	60–100	40

It is noted that the life of the dies is increased two to two and a half times.

Besides dies, other tools, such as cutting tools, are similarly treated, i.e., lathe, etc., tools, drills, screw taps, milling and thread cutters, etc. Increase in the life of the tools reaches 200 per cent. Experimental work is in hand at the factory to extend the toughening process to the reconditioning of worn cutting and measuring tools and instruments.

With the artels of the "Pavlovsk" group volume stamping and pressing constitutes the main part of the manufacturing operations. A fundamental difficulty encountered by this team is the amount of labour required in reconditioning by hand, with the usual methods, worn dies, etc. (cf. Table 22, column headed "Mechanical method"). It became necessary therefore, to find methods of improving the technology; methods which would reduce the labour and expenditure involved in the various operations of reconditioning worn dies.

This problem in the system of industrial co-operation was first solved in 1951, when the "Pavlovsk" Kirov Group applied to their industrial methods the experience of the Leningrad works, "Krasnogvardeets", in the electro-spark treatment of forging dies. In the group's section for electro-spark working two machines of the type EISK-3 of the "Krasnogvardeets" factory were installed for reconditioning the impressions of forging (shaping) dies made of steel 5KhNM, worn by use in the smith's shop. The machines are fed with 230 v d.c. from a 16 kW dynamo. The complete reconditioning of the dies comprises two operations: grinding the faces of the die and electro-spark deepening of the impression in a kerosene medium.

The faces of the die are ground to a depth of 0·2 to 0·5 mm to remove principal racks, after which the profile of the impression is treated under a regime of J=100 v, C=24 mfd, and I_r=2 amp (Russian original I_p). This takes from 0·66 o 1·5 h, according to the dimensions of the die, and using the regime stated. 'he speed of working (rate of deepening by the electrode tool) is, say, 0·005 to ·006 mm/min. After the time mentioned it is necessary to switch over to the inishing regime, namely, U of 100 v, C of 2 mfd, and I_r of 0·2 amp. Finishing nay take about 15 min. The extent of deepening of the die profile is 0·05 mm rom such working.

It is then necessary to treat the die face or impression for flash and gutter fins or seams, etc.). This is done with roughening and finishing regimes. For the ormer the regime is: U=150 v, C=234 mfd, I_r=10 amp, and rate of working, say, ·02 mm/min. The finishing regime, for die flash and gutter, takes five minutes vith a regime of 100 v, 24 mfd, 2 amp. Surface finish of the die after working ınder the finishing regime (100 v, 2 mfd, 0·2 amp) corresponds to about the ifth class of Russian standard GOST 2789-45, and fulfils the requirements tipulated for dies under the manufacturing conditions of the group. In order to educe surface roughness of the dies after electro-spark treatment in most cases hey are cleaned by honing and rubbing with fine emery cloth.

The electro-spark working of dies with an impression of relatively simple orm and of working area 2450 mm² is done with one electrode tool for roughening and finishing. After the former operation the profile of the worn electrode ool is restored in the smith's or fitting shop. For working dies of more complicated form, e.g., shearing dies, with working area of 1570 mm², two electrode ools suitably adapted for roughing and finishing are used. Electrode tools for vorking dies are prepared from red copper as follows:

(1) forging the die block with a lateral allowance for the whole profile (thickness of die-block for all articles is 30 + 1 mm),
(2) grinding two faces of the blank,
(3) marking out profile,
(4) planing or shaping the profile,
(5) bench fitting work on profile on the basis of one of the ground faces to accuracy of 0·05 mm,
(6) soldering on the stem.

To utilize more fully the tool material, in treating dies, a steel strip of the same rofile and of 5 to 10 mm thickness is in many cases welded on to the tool. Such in electrode tool is able to treat 50 die faces or impressions before it is completely used up. As in previous cases wear of the tool profile is corrected in the itting shop before proceeding to further working.

From the time of its introduction to the present, in the S.M. Kirov group, vork has proceeded daily on the reconditioning of forging dies by the electro-spark method. Three workers are engaged: one servicing the machines, and two preparing electrode tools. In one working shift, with both machines in operation, they deal with four pairs of dies for stamping scarf or lock curves and four 'magazines" for flash and gutter.

APPENDIX I

(Abridged)

INSULATING MATERIALS

1. **Lakotkan** (lacquered fabric) is formed from linen or batiste (cambric) 0·1 to 0·5 mm thick, impregnated with a light (yellow) fatty or asphaltic (black) varnish; used in insulating windings of electrical machines.

2. **Micanite** is compressed material from sheet mica and shellac, with a binder such as lead borate, waterglass, phosphoric acid (fire-resistant micanite), or copal lacquer with 2 per cent admixture of castor oil (flexible micanite). It is used in electrical machine commutators, and generally as an insulation packing or lining.

3. **Presspahn** (pressboard): this material of high quality, of 0·1 to 5 mm in thickness, is used for insulating windings in slots and grooves of machines, and for all kinds of insulating packing or lining.

4. **Soft rubber:** materials are known as rubbery when the main constituent is natural or synthetic rubber. Since caoutchouc is oxidized in air and especially in ozone, losing in this way several valuable properties, it is vulcanized, i.e. sulphur is added to it. Soft rubber contains from 2 to 12 per cent sulphur. It is used for insulating conductor wires and several kinds of cable.

5. **Sovol** is a synthetic liquid, used as a substitute for transformer oil, and, being non-inflammable, has some advantage over this oil. Owing to its high dielectric properties it is specially suitable for impregnating condensers.

6. **Fibra** (fibre or leatheroid material): product obtained by processing high-grade paper; used in those cases where a specially high quality insulating material is not required; e.g. in the production of bases and covers of low-voltage switches and the like adjusting or regulating elements.

7. **Textolite:** compressed multilayer fabric impregnated with bakelite varnish. Hot pressing is used. It is made in the form of rods of circular section and also in sheets. Textolite is tough and not brittle. It is used for panels and switchboards or covers, control panel components, insulation packing and sheathing, bushes or sleeves etc.

8. **Getinaks** (Hetinaks) is prepared in the same way as Textolite from special-grade paper; and its field of use is similar to that of Textolite.

APPENDIX II

(A) COMPOSITION OF METALS REFERRED TO IN THE TEXT

. **Hard Alloys**

The VKx series (including VK_3 and VK_8) are based on tungsten carbide and cobalt. The TxxKx series are based on titanium and tungsten carbides and cobalt; their ıardness (and brittleness) increases in the order T15K6, T30K4, T60K6.

.. **Steels**

ı0 Kh includes 0·35–0·45% C, 0·50–0·80% Mn, 0·17–0·37% Si, 0·80–1·10% Cr.
:0 Kh includes 0·17–0·25% C, 0·40–0·70% Mn, 0·17–0·37% Si, 0·80–1·10% Cr.
ıormite includes 2–1·5–2·0% C, 13·5–17·5% Cr, 1·3–2·5% Ni, 1·5–2·2% Si.
less than 2·0% Mn, less than 0·07% P and S

ShKh xx steels

Only typical compositions can be found:—

ShKh 15–1·1% C, 0·34% Mn, 1·2–1·6% Cr, 0·35% Si.
ShKh 45–0·45% C, 0·68% Mn, 0·08% Cr.

Ux steels

These (including U8) are plain carbon tool steels.

ı. **Brasses LSxx**

The number after the letter denotes copper content (59% and 62% in LS59 and LS62 ·espectively), the letter "S" denotes the presence of lead (0·8–1·9%), the rest is zinc.

(B) STANDARD REFERRED TO IN THE TEXT

GOST 2789–45 can be obtained on loan from:

British Standards Institute,
British Standards House,
Park Street,
LONDON, W.1

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