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Theoretical Foundation of Induction Quenching Parameters of Ploughshares

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Abstract: The article provides ways to reduce the wear of plowshares from the impact of abrasive soil particles, as well as the value of induction hardening in increasing the wear resistance of ploughshares, the theoretical foundations of induction hardening parameters, such as quenching depth, heating temperature, heating time, and cooling rates.

Keywords: ploughshares, resource, hardness, abrasive wear, heat treatment, martensite, quenching depth, induction hardening.

Today, the resource of the working bodies supplied for soil tillage machines in agriculture is much lower than the standards set in the technical requirements, which causes them to wear out quickly. This situation is becoming more serious due to the fact that the working bodies produced in our Republic are made of low-carbon steels that are not refined or heat-treated. As a result, agricultural producers are significantly increasing their costs due to the large purchase of these working bodies as spare parts, reducing the quality and productivity of field work and delaying the completion of work. For this reason, in today's conditions where the resources of the supplied working bodies are low, thermal, chemical-thermal treatment of them, increasing the corrosion resistance by welding modern composite materials on the working surfaces is one of the urgent issues.

The hardness of the sand in the soil is much higher than the hardness of the material from which the working bodies are made. In this case, in the process of soil cultivation, these working bodies quickly become unusable.

Studying the specific aspects and mechanisms of abrasive wear, scientists have discovered the phenomenon of a sharp increase in the relative wear resistance of materials as the hardness approaches the hardness of the abrasive particle. This incident was reported by M.M. Tenenbaum, V.N. Tkachev, R. Kiffer, D. Benezovsky, M.M. Khrushchev and M.A. Babichev, U. Ikramov, A.S. Pronikov, D.N. It is widely covered in the works of Garkunov and others. (1, 2 3, 4, 5, 6, 7, 8, 9).

Regarding this situation, M.M. Khrushchev and M.A. Babichev determined that the relative bending resistance of technical pure metals in an abrasive environment is directly proportional to their hardness (H) (4):

$$\varepsilon = b \cdot H$$

They showed three specific relationships that determine the wear conditions in the study of the effect of the ratio of workpiece material and abrasive particle hardness on wear.

material (H_m) and abrasive (H_a) is $H_m / H_a \leq 0.6$, bending resistance has a linear increasing characteristic. When the ratio is in the range of $0.6 \leq H_m / H_a \leq 1.4$, the bending strength has an increasing parabolic connection. When the ratio is $1.4 \leq H_m / H_a$, a sharp hyperbolic increase in flexural strength is observed.

Among the abrasive particles in the soil, sand particles with a hardness of up to 11,000 MPa have the most abrasive effect. The hardness of the grinding surface of the detail is usually lower than the hardness of the abrasive particle of sand (Table 1.) because the parts working in friction conditions of the machines are mainly made of iron alloys.

Table 1 showed that, the difference between the hardness of the working body hardness and the hardness of the abrasive particle consisting of quartz sand, which is present in the soil.

Table 1. Microhardness of metals and alloys

No	Material type	Microhardness, MPa	No	Material type	Microhardness, MPa
1	Quartz sand	8000-11000	9	St 20 found	4250
2	St. 10	1600	10	St 30 found	5100
3	St. 20	1800	11	Collected 45 steel	6400
4	St. 30	1900	12	Iron carbide	8000
5	Not found 45 steel	2000	13	Iron Manganese Compound Carbide	6500
6	St 20XN found	4500	14	Chromium carbide CrC	18000
7	ShX 15 found	8000	15	Tungsten carbide WC	30000
8	X12M found	5100	16	Boron Carbide BC	35000

It can be seen from the table that in the case of marked 45 steel, the microhardness of the unhardened steel is much lower than the microhardness of the abrasive particles, so the creep rate of the working body made of it is significantly higher than the creep rate of the working body made of this grade of steel and hardened. It follows from this that it is possible to significantly increase their working resource by means of thermal treatment in the production of working bodies.

Quenching the surfaces of steel products. Working bodies that work under the influence of high loads, including crankshaft necks, gear wheels, and tooth surfaces are polished only on their surfaces to make them less flexible when exposed to dynamic and cyclic loads (loads) during operation. For this, their surface layer is heated up to the temperature of heating, and after holding at this temperature for a certain time, it is cooled in water or oil. As a result, the surface layer is hardened and the core is not hardened. High frequency current, sometimes gas flame, and electrical contact heating devices are often used to heat objects up to the required temperature. The method of using high-frequency current differs from other methods in terms of high productivity and ease of automation.

Martensite. This structure is carbon alpha in iron Fe_a (C) . This structural of steels hardness will be between HB = 6000-6500 MPa. Therefore, the degree of hardening of steels is expressed by the amount of martensite in the obtained structure. It is for this reason that the process of tempering of steel is sometimes called martensite.

Usually, to determine the thickness of the hardened layer, a layer is taken from its surface to the semi-martensitic structure towards the core, and the thickness of this layer is the hardened thickness.

Since the researched ploughshares work under conditions of high loads and heavy abrasive friction, their surface layer should be made resistant to wearing using certain methods, and their inner layer should be resistant to high loads. Therefore, applying the method of heat treatment of ploughshares with the help of induction current to obtain a surface layer is the simplest, less expensive and convenient.

The dimensions of removal of ploughshares (Fig. 1) with the initial width of the nose part H = 155 mm, its removal size H_{pr} = 90 mm, and the width of the plow blade h = 130 mm, its removal size h_{pr} = 90 mm, the width of the rear face is 7-12 mm, the side thickness of the blade is equal to the thickness when bent up to 30% compared to the initial size. If the average thickness of the plowshare is 12 mm, then its scrap thickness will be 8.5 mm on average. At the same time, according to the information provided in some literature, the weight of plowshares cut to the above-mentioned invalidation dimensions decreases to 1 kg. On the basis of the above, it can be concluded that it is enough to apply the surface part of the ploughshares to a thickness of about 2 mm. It follows from this that it is this thickness that should be taken as a basis when calculating the inductor to find plowshares (10, 11, 12) .

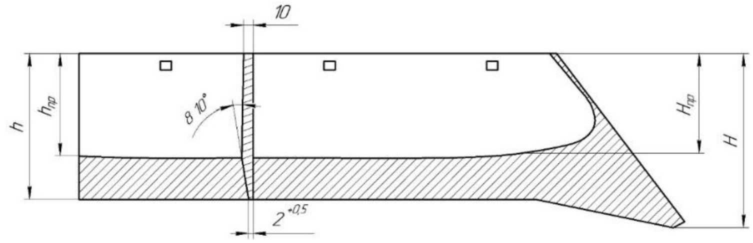

Figure 1. Structural and boundary dimensions of Lemex

The essence of surface tempering of parts is that the surface layer of the part is heated very quickly until the austenite structure is formed and then cooled rapidly (usually in pressurized water). In the last second of heating, a large temperature difference occurs along the cross section of the part from the outer surface to the inner part. In this case (Fig. 2), the structure of steel in the first zone consists of martensite and a small amount of residual austenite, in the second zone it consists of martensite, ferrite and residual austenite. Steel in the third zone, since the heating temperature of the steel in this zone is lower than the critical point As $_{1}$, as a result of cooling, structural changes do not occur in it, and it consists of initial ferrite and pearlite structures. That is why the hardness of steel in the first zone is maximally high, in the second zone the hardness is lower due to the presence of ferrite structure, and in the third zone the initial hardness of steel before hardening is preserved (13)**Error! Reference source not found.**.

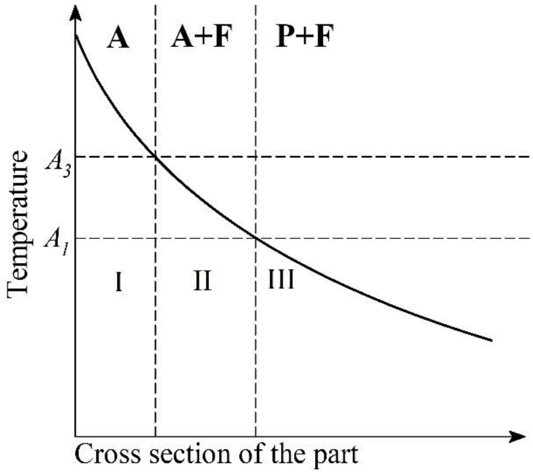

Figure 2. Curve of temperature change from the outer surface to the inner part along the cross-section of a steel part up to the eutectoid during the last second of surface heating.

The following are the main parameters of inductive welding of details with the help of high-frequency current:

1. **The depth of the buried layer x_k** , it is conditionally accepted as the distance from the surface of the detail to the layer with a martensite structure of up to 50% in its internal structure. (14)

   The choice of the optimal thickness of the coated layer is determined based on the working conditions of the part. If the detail works only in bending, then the depth of the layer of the layer is 1.5...3.0 mm is considered sufficient.

2. **Quenching time t_t** is the time it takes to heat a layer of metal up to a depth of x_k**.** In most cases, at the selected current frequency, the acquisition time represents the depth of the acquisition layer. In addition, it is the only parameter of the heating mode, precisely controlled by a time

relay and easily monitored by direct measurement. Therefore, the heating time can be considered as the main parameter of the heating mode in practice (14)

3. **Quenching temperature** T_t is t_t - a temperature reached over time, at which the desired structural changes occur in the metal.

The tempering temperature of steel depends on the amount of carbon and alloying elements in it. Carbon steels are heated to a temperature 30...50 higher than the Ac_3 curve ℃(dashed zone in Fig. 3). In this case, pre-eutectoid steels, as a result of heating, change from the initial ferrite + pearlite structure to the austenite structure, and in the process of cooling, the martensite structure is obtained by cooling at a speed higher than the critical cooling rate.

4. **Overheating of the outer layer of the detail** DT is how much higher the temperature in the surface layer of the part to be found is higher than the temperature of the inner layer x_k (14)

As the heating temperature increases, the austenite grains become larger, the processes of oxidation and decarbonization of the surface layer of the steel accelerate, and the internal stresses caused by the formation of the heat-treated part increase. The optimal temperature range for heating carbon steels is presented in Figure 3.

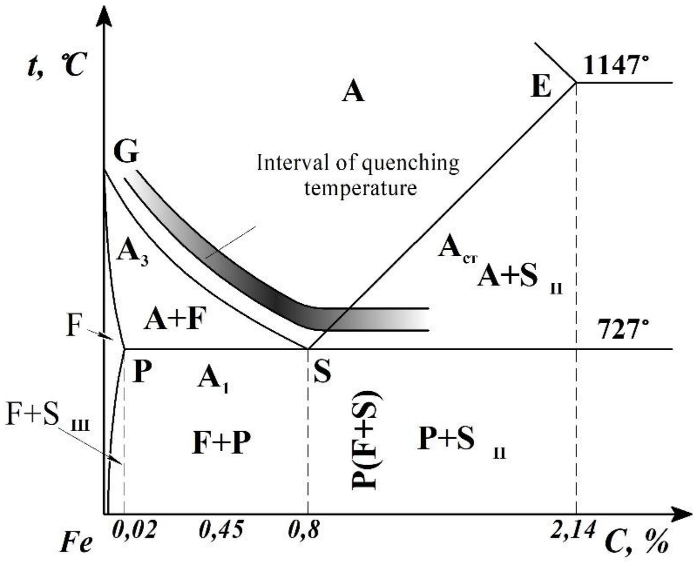

Figure 3. Optimum heating temperature range for quenching carbon steels

5. **Heating speed** v_q (℃/sec), the average temperature at the end of heating up to the specified temperature to quenched the part. In furnaces, the rate of heating details does not exceed 1 ℃/sec, and in induction heating, the rate is $10^2 \ldots 10^3$ ℃/sec is reached. As the heating rate increases, the phase changes of the steel shift to higher temperatures. Therefore, the higher the heating rate, the higher the temperature of turning the steel into austenite. In this case, the austenite grains do not grow larger, but are smaller than when heated in the furnace, because the rate of formation of austenite centers is higher than the rate of linear growth of austenite grains (Fig. 4).

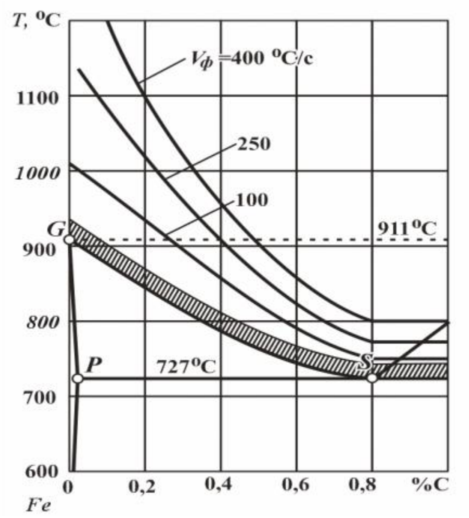

Figure 4. Effect of carbon content at different heating rates on heating temperature for forging carbon steels. The hatched zone is the temperature range of gradual heating.

6. Critical cooling rate. In tempering, the martensite structure appears only when it is cooled at a rate higher than the so-called critical cooling rate.

The lower the critical rate of formation, the higher the stability of austenite during cooling. The stability of austenite depends primarily on the chemical composition of the initial austenite. All alloying elements except cobalt increase the stability of austenite. In addition, the smaller the critical speed of the austenite, the larger the grains of austenite and the more homogeneous the chemical composition.

The speed of cooling with water depends on the pressure of the water on the surface of the part and the temperature of the water**Error! Reference source not found.**.

7. Thermal useful work coefficient *of quenching process* . The coefficient of thermal useful work of the quenching process is the ratio of the amount of heat spent on the thickness of the deposited layer to the amount of heat spent on heating the entire part. The thermal efficiency of the heating process is determined by the type of heating and the heating temperature.

There are two types of heating (Fig. 5): superficial and deep. The specific power consumed during surface heating will not be very large: $D_2 < \boldsymbol{x}_{\boldsymbol{k}}$. In case of deep heating, the specific power spent on the heated unit surface is much larger $D_2 > \boldsymbol{x}_{\boldsymbol{k}}$.

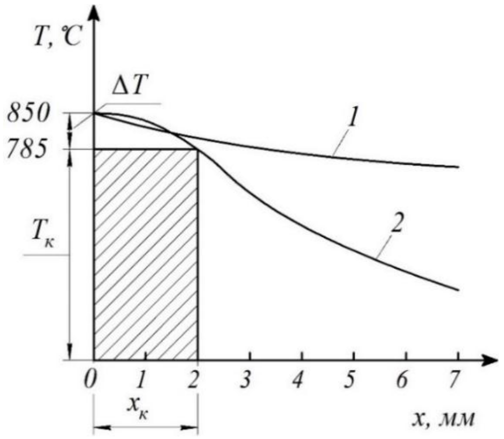

Figure 5. Two methods of heating for toning: 1-superficial, 2-deep.

In surface heating, heat is released in the thin surface layer of the part and spreads into the part due to thermal conductivity of the material.

From the above, it became clear that in all cases of surface induction heating of details, it is necessary to try to use a deeper method of heating (14).

The intensity of the induced current is different on the cross-section of the part being heated: the current density is the highest on the surface, and it sharply decreases as it moves towards the inside of the part.

It is known that about 90% of the heat is released in the surface layer of the heated part with a thickness of d . This heat depends on the current frequency (f), the magnetic conductivity of the steel (m), its specific electrical resistance (r) and is determined by the following expression (13)**Error! Reference source not found.**:

$$\delta = K \cdot \sqrt{\frac{\rho}{\mu \cdot f}}$$

where K is a constant coefficient for the steel being obtained.

is selected taking into account the specified depth of the deposited layer and the dimensions of the detail, the standard current frequency corresponding to it, the updated process of deposition, the design of the inductor and the device of deposition, the maximum load of the device and the specified performance [14; pp. 55-57].

If the surface of the workpiece is large and long, it will require too much power to heat the entire surface at the same time, which will be a process that cannot be carried out by itself or will not be economically feasible. For such details, the method of finding it continuously from one end to the other end is used. In this method of heating, the inductor and the part are continuously moved relative to each other.

In this case, the heating rate is determined as follows:

$$v = \frac{l_1}{t_k},$$

in this v- heating speed or the speed of movement of the part with the inductor relative to each other, m / s ;

l_1- the width of the inductor, m;

t_k-heating time, s.

The width of the inductor depending on the current strength is calculated by the following expression:

$$l_1 = \frac{P_g}{\pi d_2} \frac{\eta_{in}\eta_{tr}\eta_k\eta_l}{p_o},$$

where P_g −generator power , kW ;

d_2- the diameter of the inductor tube, m ;

p_o- specific power, kW / m ^{2}

The heating time is expressed by the time it takes for the part to fully heat up to the required temperature along its entire length, or it is determined by the following expression:

$$t_k = \frac{l_2}{v},$$

where - $l_2$the length of the part to be heated, m;

v- heating speed or the speed of movement of the part with the inductor relative to each other, m / s .

The method of continuously heating parts from one end to the other end allows to weld large surfaces of parts with relatively small power. In this case, it goes without saying that the search performance decreases proportionally. On the basis of the recommendations given above, it is possible to determine the frequency, power and speed of the current, taking into account the specified conditions of the acquisition. Taking into account the above information and the length of the detail, it is possible to calculate the productivity of the search.

Conclusions.

1. The analysis of the results of previous studies showed that in order to increase the resource of working bodies of earthmoving machines, it is necessary to increase their hardness to 0.6 and higher compared to the abrasive hardness of quartz sand.
2. It was found that there are ways to increase the resource of working bodies of soil tillage machines: thermal treatment (burning), chemical-thermal treatment and coating of corrosion-resistant materials on the working surface, which are considered to be economically effective for the conditions of agricultural production.
3. As a result of the conducted theoretical studies, it was determined that in order to thermally treat the working bodies of tillage machines, in particular, plow plows, it is necessary to apply a working surface layer up to 2 mm thick.
4. In order to grind the working surface of plug plows to the required thickness, the induction grinding method, which is one of the modern methods of grinding the surface layer of details today, was chosen and its main parameters were theoretically justified.

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