Choice of technology for heat treatment of large diameter gears on the basis of the system-resource approach

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Abstract. The article solves the problem of choosing a technology for heat treatment of gears of large diameter based on a system-resource approach for a particular enterprise. To solve the problem, a functional model was developed, the production resources available to the enterprise were analyzed, and the possibilities of developing solutions using system forecasting models were analyzed. Sketches of the solution were developed for transfer to the departments of mechanization and automation for further design and technological development and manufacturing.

1 Introduction

The tasks of heat treatment of large diameter gears are not trivial. The problems of their heat treatment are associated not only with the fact that they, as a rule, belong to small-scale production, the need to achieve the necessary strength and hardness at large curvilinear diameters, but also with the possibility of fitting into existing production, which, as a rule, has significant limitations in the presence of thermal furnaces, lifting equipment, availability of space, installed power capacity, etc.

Such tasks are well solved on the basis of a system-resource approach with an analysis of all available resources, a systematic consideration of the possibilities of changing technology for existing production and the involvement of various methods for solving such an engineering problem [5].

The paper solves the problem of choosing a technological solution for the heat treatment of gears of large diameter in the conditions of small-scale production and the limitations imposed by the existing production capacities. The problem is solved on the basis of a practical production problem of developing a heat treatment technology for the central gear of a rotary machine for filling drinks of the VDR series manufactured by JSC Lenprodmash.

The task set before the developers of the technology was to find a solution for induction (preferably) hardening of gear teeth with a diameter of up to 1500 mm using the maximum

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production capabilities of the enterprise. The essence of hardening consisted in heating the wheel zone along the perimeter and cooling it to obtain the required structure of the working surface of the wheel teeth.

To solve the problem, the system selected a hardening device, where the main subsystems are an inductor, a generator, a sprayer and auxiliary stands, fixtures, etc. The functional model of the hardening device as a technical system is shown below, Figure 1.

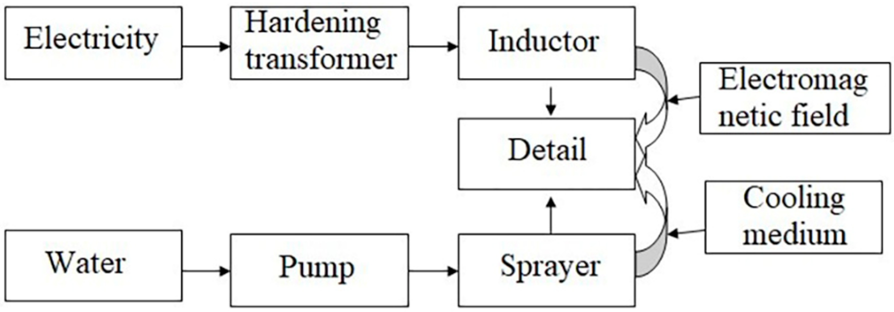


Fig. 1. Functional model of gear heat treatment.

At the first stage of the analysis, a patent study was carried out with the identification of the main stages in the development of hardening of large-sized products with the provision of hardening of their periphery [2–3]. The following steps have been identified:

1. "Female inductor" - female inductor by part type (configured around its periphery).
2. A part moving relative to an inductor.
3. Interconnected movement of the inductor and details.
4. Intensification of heat treatment by changing the system connections of the inductor together and separately with the transformer or by conjugated movement - communication gears and inductance (providing self-regulation).

At the same time, competing heat treatment systems were considered: quenching in an electrolyte, electrocontact quenching, volumetric, induction, gas-flame. Of the capacities available in the production, the heat treatment shop had a volumetric heating furnace, high-frequency current and a gas-flame unit, therefore, the main attention in the analysis of heat treatment technologies and their applicability in the conditions of existing production was given to them.

The task set before the developers included the requirements for further expansion of heat treatment of curvilinear surfaces of large diameters, which made it possible to somewhat expand the possibilities of selecting a technology. This also included the task of displacing the plant operator from the executive level and from the management level due to automation and mechanization of the hardening plant [7].

The preliminary stage of the analysis included the analysis of technologies in relation to the hardening of large-sized gears with a large diameter. According to the results of the analysis by the experts of the group of the chief technologist, HFC hardening was chosen for further development, Table 1.

Table 1. Choice of hardening technology.

Quenching (*)					
Type	**Gas Flame**	**Quenching with high frequency currents**	**Volumetric**	**Electrical Contact**	**In the electrolyte**
Disadvantages	Uneven heating and	Low power equipment	A large amount of time and energy	is not used	is not used

	insufficient surface quality	The impossibility of quenching curved surfaces	spent on quenching, low strength and wear resistance of the hardened surface		
Advantages	Simplicity and the possibility of quenching on the basis of an existing installation	The traditional method of quenching tooth surfaces	Good overall microstructure of the entire wheel	-	-
Tasks	Tasks It is necessary to solve the problem of uniformity of heating and surface cleanliness	(*) To proceed to continuous-sequential hardening of the teeth	To solve the problem of cooling the teeth of the wheel to the release temperature	-	-

Based on the results of the analysis, it was proposed to conduct further research in the direction of HFC technology, as close as possible to the capabilities of the JSC Lenprodmash plant. The results of the analysis are shown in Table 2.

Table 2. Choice of HFC hardening technology.

Quenching with high frequency currents (*)			
Type	Quenching with a ring inductor of the "tooth by tooth"	Quenching with a gear reducer of the "gear transmission" type	with a covering inductor when the detail is moving
Disadvantages	It is not possible to harden complex curved surfaces. Only a large module. Low performance	Low-power equipment. Impossibility of hardening curved surfaces	There is a greater lining of the tooth tip than the contact surface
Advantages	The working area is being heated.	The traditional method of hardening tooth surfaces.	The ability to bypass surfaces of different curvature.
Tasks	To ensure the incompatibility of the inductor and the part. To clarify the capabilities of the inductor for quenching large-sized products. To make possible the movement of the inductor in different directions.	Proceed to continuous-sequential hardening of the teeth	(*) To make a plastic reconfigurable flexible inductor. Ensure accurate copying of the part profile.

According to Table 2 and according to the results of expert evaluation, of all available technologies, HFC hardening with a flexible semi-envelope inductor or inductor built on the basis of segments is considered the most acceptable.

2 Approaches to solving the problem of choosing an inductor

The main contradiction in the system was taken to be the contradiction characteristic of the female inductor system, namely: with an increase in the diameter of the gear wheel, the current strength decreases, the required hardening temperature is not reached, and the gear wheel cannot be hardened. With an increase in the diameter of the inductor, the heating power also decreases. Thus, the physical side of the contradiction looked like this: in order to provide the required heating temperature of the wheel, due to the required power given by the inductor, the wrapping diameter should be small, and in order to cover the wheel of a large diameter, the inductor diameter should be large or, to strengthen the contradiction, you can say anyone.

The main idea in this case, accepted for consideration and capable of removing this contradiction, is the need to find a solution in which power should be generated where it is really needed [1]. To improve the ideality of the solution, it was decided that the number and quality of the functions performed by the profiles of the hardened surfaces, the degree of curvilinearity of the heat-treated surfaces should be increased, the maximum increase in the surface of a large size was achieved with a small installation size. Taking into account the requirements for use in small-scale production, it was decided to increase the versatility of the proposed technology and equipment.

3 Analysis of available and available resources

To solve the problem using the system-resource method, it is required to find internal and available external resources, which can be divided into available (ready-made) and derivatives (additional and servicing or secondary).

Production resources: equipment: ready: welding transformers, hardening transformers, inductors, furnace, flame cutting; derived resources: air ducts, water pipes, electricity, production areas, etc [6].

Energy resources: available - HFC, gas flame, furnace heat; available functional production resources are shown in the diagram, Figure 2.

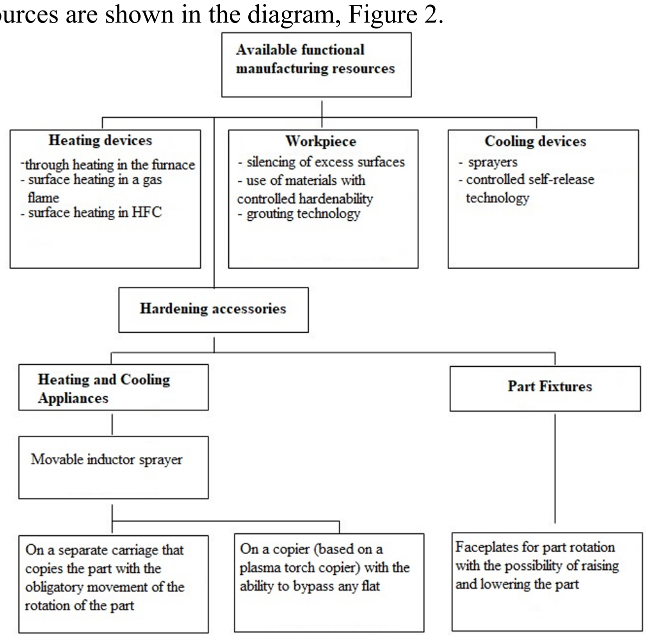


Fig. 2. Available functional manufacturing resources.

4 Description of existing available technologies

Available technologies available in production and their main characteristics are listed below.

Hardening with through heating

1. Hardening with preheating. It consists in heating the part to the tempering temperature in the furnace, installing the heated part in the enclosing inductor-sprayer and hardening. Advantages: no need for complex moving devices. Disadvantages: Fast operation required, hot workpiece difficult to set up, requires a special transport device to eliminate buckling of large flat parts.
2. Carburizing with the replacement of used steel 45 with st20. It consists in carburizing the gear teeth, hardening and tempering. Advantages - the ability to use existing technology. Disadvantages - a decrease in the strength characteristics of the entire wheel when replacing steel.
3. Use of steels with adjustable hardenability. The technology consists in heating the part to the hardening temperature, hardening with holding in the medium to a layer depth of 2-3 mm. It is possible to select steel for the normalization operation instead of hardening.

Quenching with flame heating

1. Gas-flame heating of a gear wheel with an annular squirrel-wheel burner. The technology consists in installing a gear wheel in an annular burner; hardening the gear by lowering it into an oil bath. A sketch of the technology is shown in Figure 3.

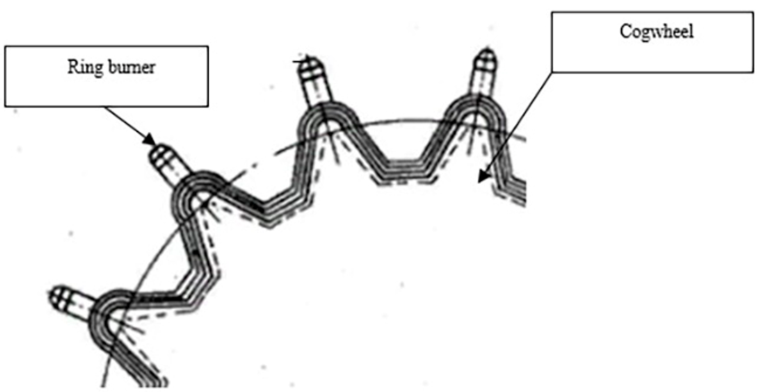


Fig. 3. Sketch of the technology of gas-flame hardening with an annular burner of the "squirrel wheel" type.

Gas-flame heating of the gear wheel on the basis of the gear wheels with the module m = 2-8 and SA-400 available at the factory could be carried out on the existing hardening machines UGZ58 or on the basis of copiers of the ASSh-70 flame cutting machine for oxygen cutting. A decommissioned radial drilling machine could also be adapted for the tasks of flame hardening [10].

Hardening with HFC

1. Hardening on the type of "cavity by cavity" and "tooth by tooth". The sketch shows Figure 4.

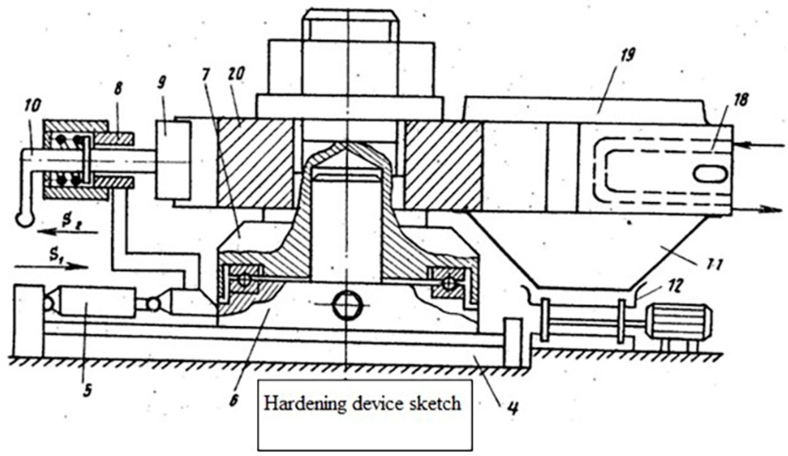
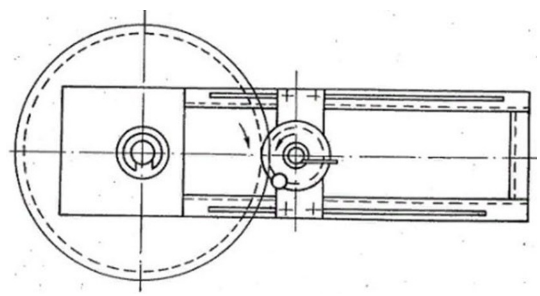
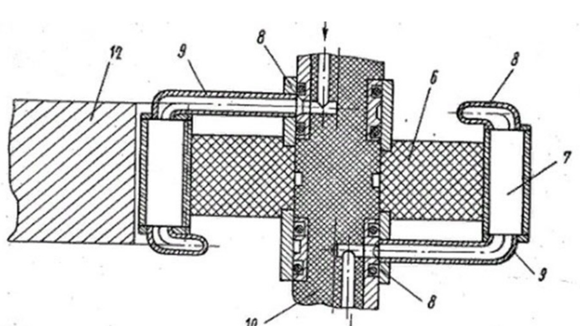


Fig. 4. HFC hardening technology "cavity by cavity", "tooth by tooth". 4 - the frame; 5 - fixing the retainer; 6 - the working plate of the device for rotation; 7 - the rotating table; 8 - the bushing of the retainer; 9 - the retainer; 10 - the handle of the retainer; 11- the holder of the quenching inductor; 12 - the elements of electrical pathways; 18 - the inductor; 19 - the cover of the inductor; 20 - large-module gear wheel.

1. Hardening according to the type of "running" of the part with an inductor
   It can be made on the basis of machine elements for large-sized parts, available at the factory, Figure 5.



a)



b)

Fig. 5. Sketch of the hardening technology according to the type of "running" of the part with an inductor. a) a running-in circuit with a cogwheel on the machine; b) a circuit of a rotating quenching inductor: 6 - an insulating ring; 7 - a water-cooled inductor; 8 - fasteners; 9 - a cooling water pipeline; 10 - an inductor rotation column; 12 - a cogwheel.

Available or available resources were considered for further analysis.

Information resources: ready-made: parts - analogues, time relays, surface characteristics of the part during heat treatment (thermal field, color field), experienced thermists; derivatives: surface hardness, the possibility of obtaining information on the hardening microstructure from thin sections.

Space resources: - these are suitable parts for the spatial arrangement of the gear: finished: the possibility of locating the most characteristic curved surfaces in space; derivatives - the use of trolleys, hoists, lifts, etc.

Time resources: ready - when one surface is heated, the already heated surface is simultaneously cooled (possibility of tempering the adjacent surface of the part); derivatives: self-removal, self-substitution for hardening.

Functional resources: ready-made: the possibility of combining technology with hardening of flat, long, curved, shaped and other surfaces; derivatives - oil baths used for hardening, a carburizing plant located nearby.

System resources: changing the connections between the inductor-sprayer and the part when combining the movement of the part with the movement of the inductor-sprayer; selection of such modes under which self-release occurs.

Supersystem resources: resources of related and final industries, for example, machining and the possibility of using other force fields (for example, background - gravity, weather, etc.).

To analyze the degree of the required deployment (folding) of the technology, the functional center of the technology was determined, namely: the generator - the inductor, where its operational zone is the emerging electromagnetic field of the inductor in the surface layer of the part and an additional zone - the water supply from the sprayer with the appropriate device. The part removal zone represented another auxiliary zone. The main connections within the hardening system are shown below:

- Energy - the energy of the magnetic field is converted into a thermal field in the details;
- Real - inductor-sprayer and parts are conjugated;
- Functional - the sequence of heating and cooling must be observed;
- Informational: between the inductor, the detail and the sprayer there should be feedback, namely: "Inductor - detail" - heating level; "Inductor - sprayer" - hardening speed; "Sprayer - detail" - self-release level.

5 Requirements for the development of solutions and directions taken into account

The following lines of development have been adopted:

1. Improving the quality of performance of functions: changing the inductor according to the profile of the part; running in the profile of the part with an inductor.
2. The inclusion of additional subsystems that expand the possibilities of heat treatment: columns for vertical products that can move large and heavy parts; engines; copiers; communication relay (time, inductance, etc.).
3. Increasing the hierarchy in the system; two-turn inductors; complication of sprayers (showers, systems of drop formation and improvement of spraying and drop formation); complication of the connection between the inductor, the sprayer and the part; production of prefabricated inductors from modules; hardening by segments of large parts or surfaces; use of heating inductors and main heating inductors [8].

4. Creation of the reticular system: parallel production of different parts of different configurations; self-tuning of the inductor to any profile.
5. The use of additional production resources according to the model of transition to the supersystem: the connection of dissimilar elements from existing production resources, for example, the use of columns of welding transformers for a hardening device and faceplates from machine tools for precise installation of large parts and ensuring their rotation.

6 Using development models to predict and select technology

The progress of the analysis and the possible applicability of the models is shown below. Development models are borrowed from [1]. The simulation also used the results of a patent search and identified solutions that reflect different directions of hardening of curved surfaces of large diameter.

Creation of bisystems: An example. Using the possibilities of double hardening at the same time on the outer and inner surface of the part.

Creating a system with shifted characteristics: Example: an inductor with different thicknesses of current-carrying sections in order to create inductance of different inductance.

Creation of a supersystem from alternative systems: combining carburizing with HFC hardening; combination of flame heating with HFC sprayer; use of an HFC fixture with bulk hardening; carrying out HFC quenching after thermal improvement to obtain a wear-resistant and hard martensite-based surface (HFC step) on a sorbitol structure (thermal improvement step).

Creation of inverse systems: the use of thermal cycling using spring elements with tension control by a reverse spring, providing cyclic heating-cooling at a given temperature.

Collapse model use: minimal - make everything close in place; partial - the union of the inductor and the sprayer; complete - integration of the part - inductor and sprayer and accessories.

The last point includes: the elimination of duplication, namely, all devices are made on the basis of one rack; cooling with one sprayer; cooling with one medium, etc.

The combination of subsystems and the merging of their functions on the example of an air duct can be performed as follows: the air duct can be used both for a pneumatic cylinder, for air cooling, and for hardening; parallel heating and cooling.

Complete curtailment - the transition to a substance that provides properties without hardening, for example, to new materials that can be hardened with minimal heating.

Using the dynamic controllability model: static - hardening only by female inductors that need to be changed; multifunctionality - hardening of dissimilar profile and other surfaces; using a software approach, for example, using different programs to perform different functions, for example, programming changes in the hardening rate depending on the part of the surface segment being rolled; changing the elements of the tool - the use of flexible inductors, the use of copiers available in the production; an increase in the degree of freedom - from heating in one direction to heating in several cavities of the part at once, in particular, the use of a copier to organize plane-parallel and complex motion [9].

Using the model to move to the micro level: hardening of steels with reduced (controlled) hardenability; control of material properties with the help of carburizing available in the production; deposition of a surface conductive layer on the surface of the part to increase the hardenability.

Using the model of changing the active field and its dynamization: magnetization of the part before hardening.

Using the controllability enhancement model: inductive coupling to enhance the self-controlling tempering mechanisms; coordination of movements of elements of the heat treatment system; the use of a flexible inductor used in the process of bypassing the surface of the part with the possibility of concentrating the magnetic flux in certain places of the part.

Use of the controllability improvement model at the micro level: Present situation: Only the macro level is used - the inductor is made according to the shape of the part. Further possible transitions: transition to the use of subsystems - segment and prefabricated inductors; transition to highly dispersed systems - an inductor with a liquid magnetic circuit, powdered ferrite cores, an ice sprayer that takes the shape of a surface; transition to the micro level at the level of microstructures - a dielectric liquid that changes its properties under the influence of a current or a magnetic field; magnetic fluid that is attracted to the workpiece, in which the inductor fits the workpiece exactly [11].

The use of the matching-mismatch model: direct - an increase in the diameter of the part leads to an increase in the diameter of the inductor, an increase in the diameter of the inductor leads to an increase in the power of the equipment, an increase in the diameter of the part increases hardening tanks, transport carts, lifting equipment, hardening devices, etc.; the opposite - increasing the diameter reduces the throughput, increasing the diameter of the inductor reduces the total inductance.

7 Solution selection

Despite the sufficient potential of flame hardening, taking into account the low requirements for surface finish of large-modulus gears, the representatives of the plant opted for HFC. The concept of a hardening machine based on the available fixtures according to Figure 7 was adopted as the basic option, which corresponded to the level of technology sufficient for small-scale production. The fixture can be used for gears and gears of smaller sizes. At the same time, the specialists of the plant noted that significant opportunities are created by combining pre-heating with a gas flame burner and final heating of HFC. A systematic consideration of the problem of hardening showed that it is possible to develop on the basis of the additional use of the identified auxiliary resources present in the enterprise, especially the use of time resources, as most often associated with the requirements of the production plan [4]. Among the development models for the selection and development of technology, experts noted the possibility of using steels with controlled hardenability, which eliminates the need for a tempering operation. The practical result of solving the problem was the transfer of sketches of the fixture according to Figure 7 to the department of mechanization and automation for further development and manufacture with inclusion in the additional part of the current year plan.

8 Conclusion

The tasks of technology selection for specific production conditions differ sharply from the general tasks of technology selection. Here, many factors must be taken into account, which depend on the available derivative resources, coordination with the maximum possible range of parts, taking into account the loading of thermal capacities in the conditions of limitations of small-scale production of gears. A phased analysis of resources using system development and forecasting models applied to the technology of hardening gears of large diameter in a specific production environment made it possible to identify the optimal solution in these conditions.

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