Action of Pulse-Magnetic Fields on Liquid and Crystallizing Metal. Prospects for Development of New Technologies

V. A. Glouschenkov[1], **D. G. Chernikov**[1], **A. J. Igolkin**[1],
F. V. Grechnikov[2], **R. J. Jusupov**[2]

[1] Samara State Aerospace University, Russia
[2] Volga Branch of the A. A. Baykov Metallurgical Institute, Russia

Abstract

Pulsed-magnetic fields are used for execution of a whole complex of technological processes: dividing, forming, assembling, welding and others. In all these technologies half-finished products from sheets, sections and tubes are used as billets.

Action of magnetic fields on a cast metal is known in the metallurgy production, for example, casting to an electromagnetic crystallizer. In spite of a high electrical resistance of a melt and owing to low mechanical resistance of a liquid metal the use of high-intensity pulse-magnetic fields (PMF) in technologies of mechanical engineering is of interest. Even the first exploration experiment showed high efficiency of such action. At energy of 1, 2 kJ a portion of the melt under the action of the PMF has flown more than 4 m, spread in the form of a thin film on the ceiling and solidified.

The paper presents three basic technological schemes of such action: with influence through a wall of a magneto-transparent crucible; by an immersion inductor; and action from the surface.

Factors accompanying such action are:

- *added sources of heat – as a result of flowing of induced eddy currents through the melt;*
- *force action on the melt responsible for passage of waves of stress and metal flows.*

Action of these factors is controllable both in intensity and in direction.

The temporal action of the pulse-magnetic field on a liquid and crystallizing metal (LCM) is to be matched with a curve of cooling the melt: either on the portion above the crystallization area or on its different portions, that is, at different relationships of solid and liquid phases.

Factors of action of the pulse-magnetic field change temperature conditions of crystallization influence on the number of centers of crystallization and, as the consequence, change structure and properties of cast metal.

The paper presents results of first studies on action of the pulse-magnetic field on a LCM which testify that such action is real and good. This has determined the prospects for development of new technologies in metallurgy (forming of an ingots' structure, stirring of a material, rolling of cast metal and so on) and in mechanical engineering (in casting, stamping, welding and others).

Keywords

Casting, Impact, Grinding

1 Introduction

Pulsed-magnetic fields are used for execution of a whole complex of technological processes: dividing, forming, assembling, welding and others. In all these technologies half-finished products from sheets, sections and tubes are used as billets.

Many researchers treated a possibility of using the action of the high-intensity PMF on a liquid and crystallizing metal skeptically. This is primarily associated with that the efficiency of pulse-magnetic processing reduces when electrical resistance of the processed material (solid metal – melt) increases. There are many other technical difficulties on the way to realization of such processing, for example, provision of performance of the inductor at elevated temperatures. But on the other hand, it is tempting to use the effect of decrease of mechanical resistance to deformation down to “zero” – for a metal melt. Moreover the positive experience of application of magnetic fields to cast metal in metallurgy production is known, for example, casting to an electro-magnetic crystallizer [1].

All these urged the authors on carrying out the first exploration experiment, the essence of which was in the following. The crucible, containing a melt of an aluminum alloy, was placed inward of the multiturn inductor for reducing. The giver of the level of the energy of the pulse-magnetic installation (МИУ-10) was moved to the lowest position appropriate to the minimum level of energy. After discharge of the МИУ-10 the melt was missed in the crucible. Having flown four meters, the metal “solidified” on the ceiling in a thin layer form. The experiment showed the efficiency of pulse-magnetic processing and good prospects for development of this direction.

2 Factors of Action of High-efficiency Pulse-magnetic Field on Liquid and Crystallizing Metal

The authors determined that basic interrelated factors of action of the PMF on a metal melt are: current intensity (I) in the discharging circuit, pressure (P) of the PMF on the liquid metal, which is specified by magnetic field intensity (H_0) and its related value of the skin layer (δ), a number of pulses of action (n), duration of pulses of action (t), temperature range of action (Tp) (before beginning of crystallizing or at the stage of crystallizing).

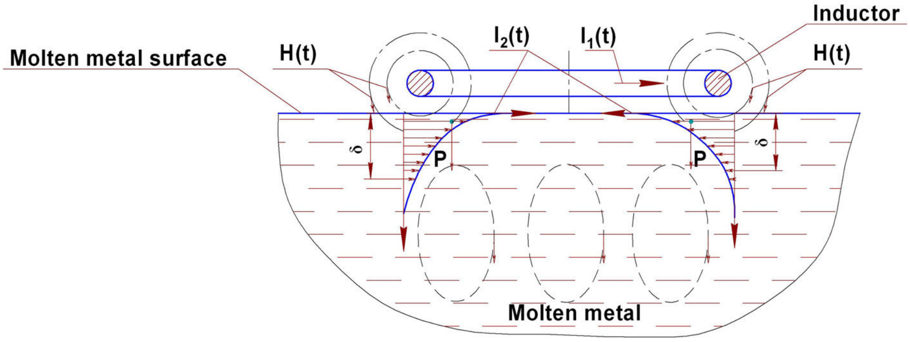
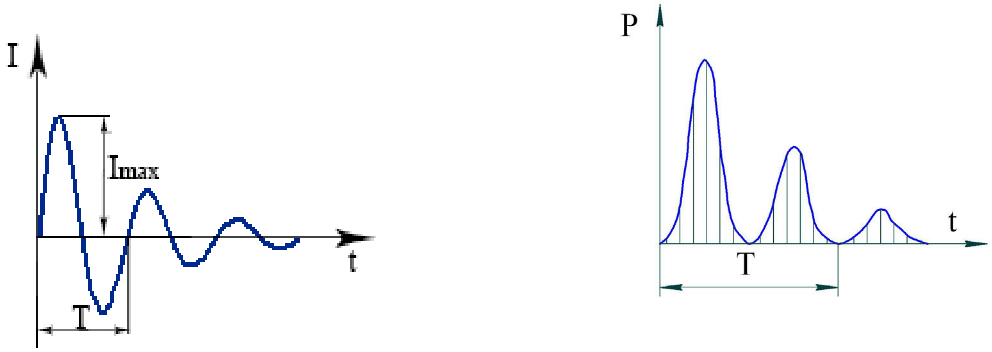


***Figure 1:** Scheme of action of pulse-magnetic fields on a liquid and crystallizing metal*

One possible scheme of action of pulse-magnetic fields on a liquid and crystallizing metal is shown in Figure 1.

Under the magnetic field action the eddy currents are induced in the melt which are added internal sources of heat. Also electro-dynamic stresses appear which give rise to wave effects and metal flows. Propagation of shock waves has a beneficial effect on the process of thickening the metal, degasification, forming of a fine-grained structure. The arising metal flows intensify crystallization and change conditions of crystallization. Directionality of the metal flows is primarily dependent on a shape and disposition of inductor systems.



a) b)

***Figure 2:** Discharging current of an inductor*

Electro-magnetic pulses of current are sinusoidal damping signals with the duration (t) of 50…150 µs and with the current amplitude of 10…50 kA (Figure 2).

The net pressure of the PMF is defined by the following expression:

$$p = \frac{\mu_0 \cdot H^2}{2} \tag{1}$$

where H – magnetic field intensity at the surface of metal melt from the side of the entry of the field.

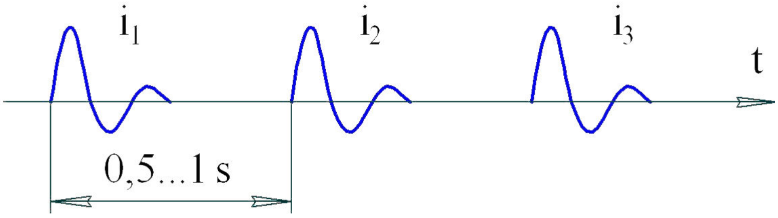


Figure 3: *Diagram of discharger pulses*

Such force and heat action can be repeated (n) with the temporal interval between pulses of 0,5…1 s (Figure 3).

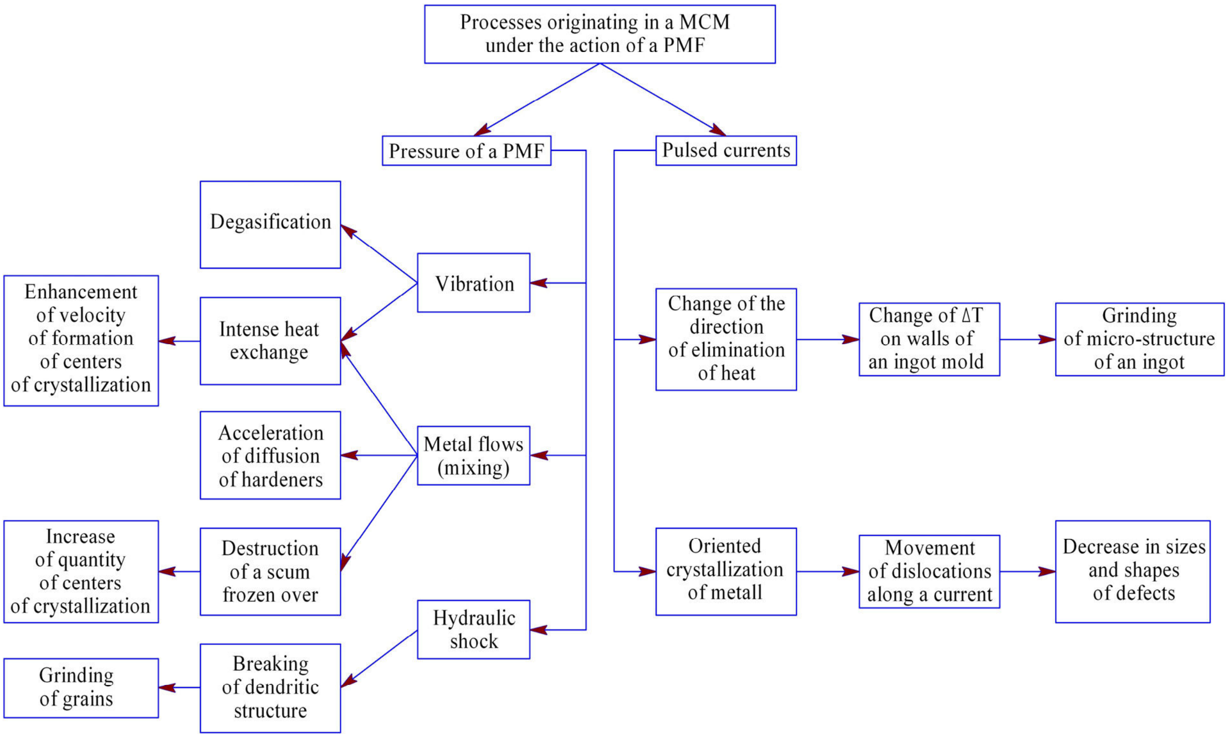


Figure 4: *Assumed mechanisms of action on a metal melt*

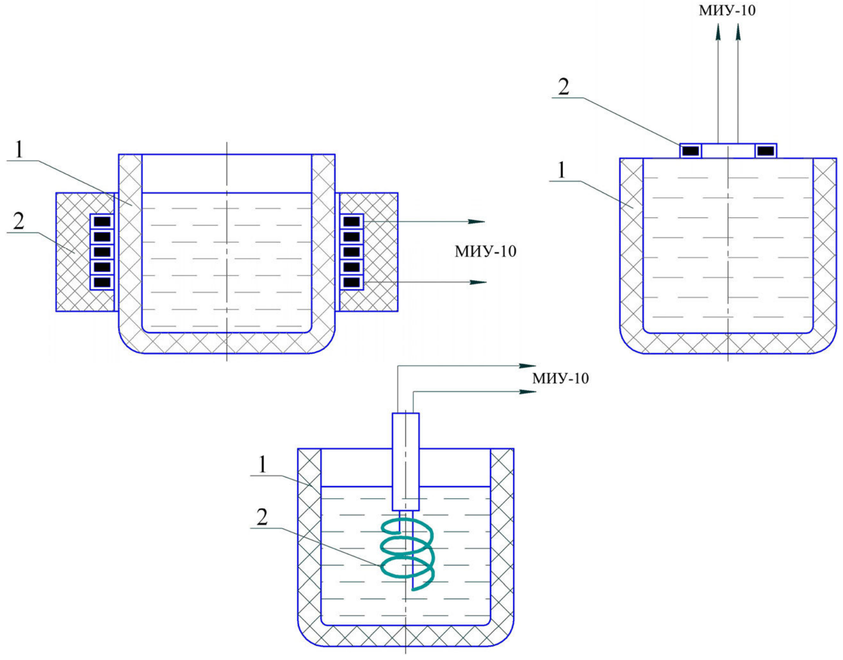
Analysis of the influence of these factors allowed making some assumptions about mechanisms of action on a metal melt which appear under the effect of the pulse-magnetic field of high intensity (Figure 4).

3 Technological Schemes of Pulse-magnetic Action on Cast Metal

Purposes of pulse-magnetic action on cast metal can be different, for example, stirring of a metal melt for intensification of a process of solution of hardeners, production of a homogeneous structure, production of a fine-grained structure, new technologies. Three standard technological schemes were developed for realization of these purposes (Figure 5):

- with the radial action of the PMF on a metal melt (Figure 5a);
- with the axial, surface action of the PMF on a metal melt (Figure 5b);
- three-dimensional pulse-magnetic processing of a metal melt with an immersion inductor (Figure 5c).

For performing the first scheme (Figure 5a) use can be made of inductors similar the inductors which are applied in pressing of metals by the PMF but either with the additional insulation of turns to offer the prospects of operation at elevated temperatures or being cooled. For this scheme a crucible must be made of a magnetically transparent material.



a) b) c)
1 – a crucible; 2 – an inductor.

Figure 5: *Standard technological schemes of pulse-magnetic processing of a metal melt*

The second scheme of pulse-magnetic action on a metal melt (Figure 5b) corrects the fault of the first scheme. The distance between the inductor and the surface of the melt is a minimum providing heat resistance of insulation.

The third scheme (Figure 5c) has the similarity to the scheme of processing a melt by ultrasonic oscillations but with the considerably more intensive action. In this case the following demands are made on an inductor: it must have the reasonable resistance to fire and be made of a chemically neutral material relative to the melt. Such scheme makes it possible to process the melt over all volume or in individual zones. For the directional action inductors can be placed asymmetrically, at an inclination; several inductors can be used in accordance with the set task.

4 Results of Experimental Investigations

The influence of parameters of the action of the high-intensity pulse-magnetic field on physico-mechanical properties of binary silumins was assessed in this exploration work with two first standard technological schemes.

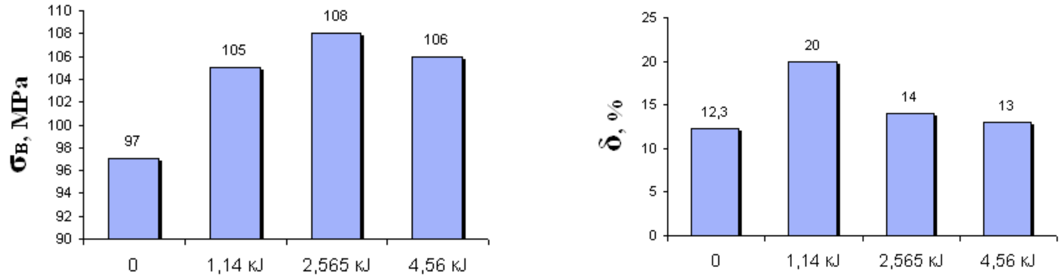
For pulse-magnetic processing by the first scheme, three types of alloys were used which have a silicon content of 1,2%, 6% and 12%. A macro-crystalline stock was used which was produced while crystallizing a melt in the graphite crucible in the sand fill.

The procedure of performance of the experiment consisted in the following. The crucible and a weighed portion of a particular alloy were heated at the crown of the furnace up to 200 ºC after which they were charged into the smelting resistance furnace. Temperature in the furnace was maintained constant, 780 ºC. At the specific temperature the melt was removed from the furnace and was located in the heat chamber with a multi-turn inductor. The chamber was covered by a cap with a thermocouple built-in.

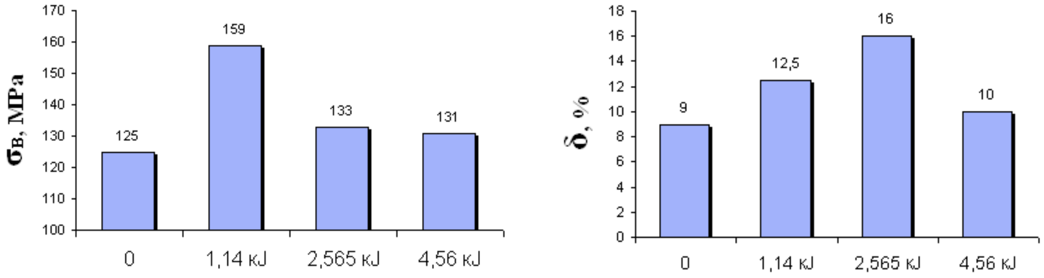
As soon as the temperature of the melt reached a prescribed value, pulse-magnetic processing was performed at different energies of 1,14…4,56 kJ according with the first technological scheme. Parameters of processing are given in Table 1. After processing by the PMF the melt was poured into the chill mold heated to 250 ºC to produce separately founded samples. Then the feedhead was removed from the samples and the samples were tested on a tensile testing machine.

Composition of an alloy	Parameters of pulse-magnetic processing (PMP)		
	Temperature of PMP, ºC	Energy of discharge of the pulse-magnetic installation, kJ	Temperature of pouring to the chill mold, ºC
Al+1,2%Si	740	1,14÷4,56	720
Al+6%Si	730	1,14÷4,56	720
Al+11,7%Si	670	1,14÷4,56	660

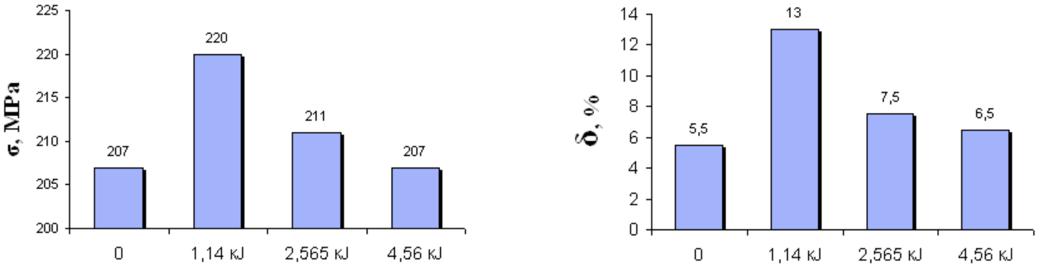
Table 1: *Parameters of processing of melts by the pulse-magnetic field*



a) Influence of parameters of PMP on mechanical properties of the alloy Al+1,2%Si.



в) Influence of parameters of PMP on mechanical properties of the alloy Al+6%Si.



c) Influence of parameters of PMP on mechanical properties of the alloy Al+11,7%Si.

Figure 6: *Influence of parameters of PMP on mechanical properties of binary silumins*

The results of mechanical tests of alloys depending on regimes of PMP are presented in Figure 6.

As the result of the exploration experimental investigations the following conclusions may be deduced.

1. The positive influence of PMP on mechanical properties of binary silumins was determined.
2. Depending on a silicone content and parameters of PMP, a maximum in increase of mechanical properties comprised (Table 2):

Al+1,2%Si	(2,565 kJ)	σ_B	11%
	(1,14 kJ)	δ	62%;
Al+6%Si	(1,14 kJ)	σ_B	27%
	(2,565 kJ)	δ	78%;
Al+11,7%Si	(1,14 kJ)	σ_B	6%
	(1,14 kJ)	δ	by the factor 2,4.

Table 2: *Maximum in increase of mechanical properties comprised depending on a silicone content and parameters of PMP*

For PMP by the second standard scheme the alloy АК9ч of Al-Si system was chosen as the subject of investigation.

For the study and control over physical processes taking place during the pulse action, the procedures of experimental investigations of parameters of a process were developed. Among such parameters are:

- the value and distribution of temperature fields with height of the cast;
- the value of the pressure pulse passed through the LCM;
- the value and distribution of pressure of the PMF in the system “inductor – LCM’s surface”;
- values of currents being induced in the LCM; and others.

It should be noted also that a peculiarity of the process of the pulse action is its fast progression and singleness. In this connection added demands are imposed upon the procedures being developed, main of which is the interrelation of temperature, energetic, force parameters of the process of crystallizing a metal and parameters of the magnetic field acting on it.

Figure 7 presents a scheme of action of the PMF on a melt and arrangement of thermo-electric transducers and pressure sensors.

It is possible to acquire a familiarity in more detail with the description of procedures of experimental investigations of parameters of action of the PMF on a LCM, with the results of these experimental investigations as well as with technique of the experiment in the work [2].

Analyzing the results of mechanical tests of check samples and samples processed by the PMF it is possible to note the following: maximum values of ultimate strength (σ_B) and specific elongation (δ) were reached at the energy of discharge W=2,565 kJ and a number of pulses n=3, increment of properties is 20% for σ_B and 56% – for δ. Moreover pulse-magnetic processing of the melt reduced porosity of casts from 2-3 down to 1-2 point, aided to equalization of content of key components (Si, Mg) through the height of a cast and, at the same time, to their movement to the upper zones. Nature of distribution of heavier components (Fe, Mn) is reverse, enriching of the lower zones.

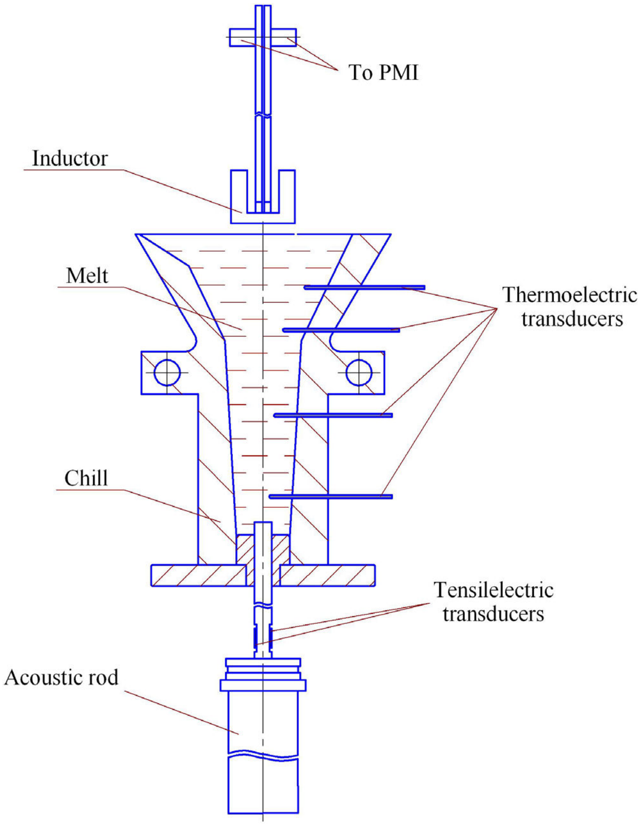


***Figure 7:** Scheme of action of the PMF on a metal melt*

Such high efficiency of pulse-magnetic processing of cast metal made it possible to determine the areas of possible application of this type of force and heat action in different technologies of mechanical engineering (Figure 8).

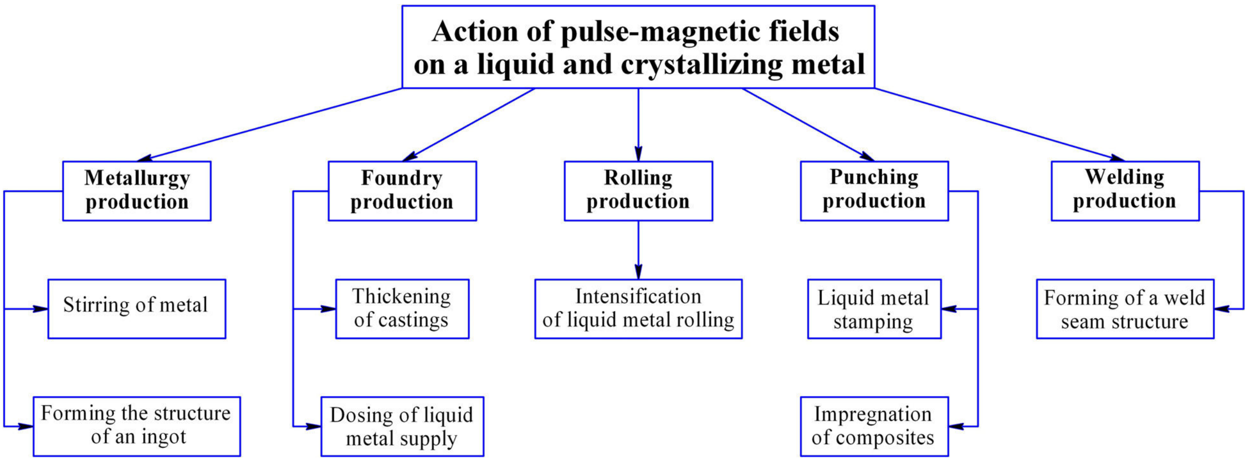


***Figure 8:** Application of pulse-magnetic processing in different technologies of mechanical engineering*

5 Conclusion

The present project is supported by the Russian Fund of Fundamental Research. Authors see the subject-matter under discussion as a promising direction and consider that it is necessary to continue more system and in-depth investigations.

References

[1] *Getselev, Z.N.; Balahontsev, G.A.; Kvasov, F.I.; Cherepok, G.V.; Varga, I.I.; Martynov, G.I.:* Uninterrupted cast to an electromagnetic crystallizer. M.: Metallurgy, 1983, p.152.

[2] *Glouschenkov, V.A.; Igolkin, A.Ju.; Chernikov, D.G.; Nikitin, V.I.; Vyalov, B.V.:* Multi-phase and multi-component materials under dynamic loading. 10th European Mechanics of Materials Conference (EMMC10), 2007