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MHD LABORATORY'S WORKS FOR NON-FERROUS METALLURGICAL APPLICATIONS

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МГД РАЗРАБОТКИ В ОБЛАСТИ ЦВЕТНОЙ МЕТАЛЛУРГИИ

Дан обзор промышленных разработок Лаборатории магнитной гидродинамики (Харьков, Украина) в области подачи, транспортировки и дозирования цветных металлов.

During last 15 years MHD Laboratory (Kharkiv, Ukraine) has made several working-out and starting-up of MHD systems for metallurgical applications. MHD systems provide pumping, transportation, dosing of alloys or liquid metals with temperature up to 700 °C (fluid media – alloy aluminum-zinc, metals: zinc, tin, lead, gallium, sodium, potassium, rubidium, lithium). In base of developments then are original schemes and technologies created in Laboratory and protected by 24 patents.

Newness of devices is that main part of system – MHD pump does not have an external cooling, its cooling realizes by heat transfer to own liquid metal. In these machines high temperature electrical insulation and special technologies have been used; that ensures the creation of reliable highly productive MHD machines. This is principal difference from similar workings-out of other organizations.

In present time in metallurgy there are in use the pumping devices based on mechanical force (coercion) on liquid metal – mechanical pumps, pneumatic grabs, ladles. The use of above named devices are connected with high expended energy, considerable losses of metal, low capacity and reliability. Main advantages of MHD pumps for metallurgical equipment compare with mechanical devices are:

1. Absence of mechanically moving parts, contacting with moved liquid metal, full integrity of channel.
2. Control of performances of metal flow directly by changing of electrical parameters (voltage and current).
3. Intensification of pumping process.

Offered equipment, based on MHD pump, has following areas of metallurgical applications:

– transfer of liquid metal from work pot (bath) to reserve pot for inspection of pot walls and in emergency situations;
– dosed supply of metal;
– casting of motor rotors by aluminum;
– units for obtaining pure alkaline metals.

1. Systems of MHD pump for moving off the liquid metal from work pot. Technology of putting the hot coating on the sheet rolling metal or machine parts by means of immersion into liquid metal needs in periodical moving off the liquid metal from work (coating) pot during planned or forced stops.

In present time for moving off the melted metal from pot ladles or mechanical pumps are used. But first method is unfit in emergency situations and dangerous for men in duty, mechanical pumps are difficult for exploitation and not enough reliable. In particular, imported mechanical pumps used in coating rolling shop of plant "Severstal" (Cherepovets, Russia) have disposable guarantee use. Replacement mechanical pumps by MHD (electromagnetic) pumps permitted to solve the problem of effective moving off the melt with multiple use of equipment.

System of MHD pump contains:

– induction three-phase immersible MHD pump with cooling to the melt of pot;

– the power supply control devices (an induction regulator, control devices, control desk), providing smooth regulation the capacity from zero to face value;

– melt transportation tube connecting MHD pump with receiving vessels;

– a cross arm for lifting the pump and tubes and for control of their position in the pot.

Beginning 1980 to 1993 Laboratory developed, manufactured, tested and delivered to customers 4 systems of MHD pump, which don't have, as far as we know, analogies abroad:

1. System of MHD pump (АМНЦ-7) for pumping over the zinc melt from work pot (bath) with capacity 500 tons to reserve pot for Machine-Building Plant (Pervomaysk on Bug river, Ukraine). Period of development and manufacture 1980–1987, starting up – 1987, system has worked successfully more then 8 years;

2. System of MHD pump (АМН-11АЦ) for pumping over the alloy aluminum-zinc (55% aluminum, 45% zinc) from work pot with capacity 55 tons to receiving vessels for coating workshop of plant "Severstal". Period of development and manufacture 1989–1993, starting up – 1993, system has worked successfully 2 years;

3. System of MHD pump (АМН-13Ц) for pumping over the zinc melt from work pot with capacity 80 tons to reserve pot and on the contrary for cold-rolling workshop of Ilich plant (Mariupol, Ukraine). Period of development and manufacture 1992–1994, starting up – 1994.

Table 1

Main parameters	АМНЦ-7	АМН-11АЦ	АМН-13Ц	АМН-14С
Working media	Zinc	Aluminum-zinc	Zinc	Lead
Media temperature, °C	460	up to 710	460	550
Capacity, t/h	400	300	160	200
Height of lift, m	3.8	3.8	2.7	4.5
Pump phase current, A	≤ 420	≤ 220	≤ 220	≤ 380
Line voltage, V	220	300	230	350
Period of permanent work	1 h 15 min	20 min	30 min	Permanently
Pump mass, t	2.5	1.4	1.0	2.5
Dimensions of pump* $h \times a \times b$, mm	1500×345×525	1000×345×525	800×345×525	1500×345×525
Power supply source	Induction regulator ИР-74/40	Auto transformer АТРМК-250/0,5	Induction regulator ИР-59/22	Induction regulator ИР-59/32
Mass of pump system, t	5	1.5	1.2	3
Pot melt capacity, t	500	55	80	–

*Without a dimensions of nozzles, cable pipes, legs.

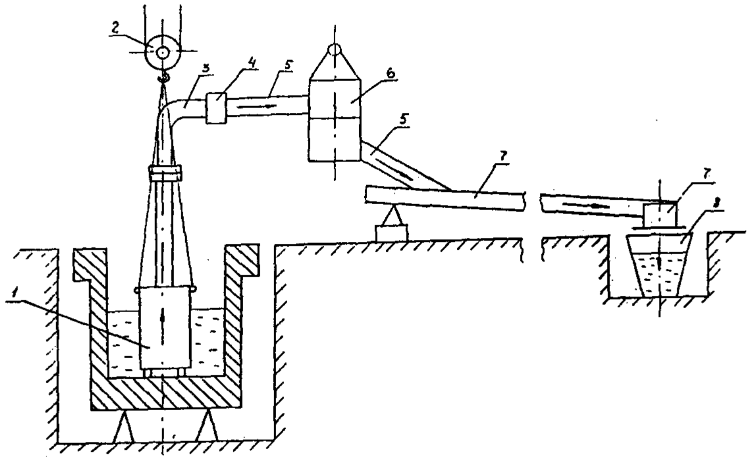


Fig. 1. Scheme of immersible MHD pump system for transfer the alloy aluminum-zinc in coating workshop, plant "everstal". *1* – MHD pump; *2* – suspension bracket unit; *3* – knee; *4* – flange connection; *5* – chutes; *6* – storage; *7* – trays; *8* – moulds.

4. System of MHD pump (AMH-14) for permanent delivery of lead to metering device feeder for lead-zinc workshop of plant "Ukrzinc" (Konstantinovka, Ukraine). Period of development and manufacture 1992–1993, unit was delivered to customer in end 1993.

In Table 1 main parameters of systems are listed. The performances of first 3 systems were obtained in period of units exploitation.

The systems (units) differ from each other mainly by kind of melt, level of melt temperature, dimensions of immersible pump, kind of hydraulic tubes connecting pump with receiver vessels. Hydraulic tube in Cherepovets and Mariupol schemes consists of chute, storage and system of trays. Tube is split because in workshop part of it is often in use and doesn't connected with lift-transportation mechanism (Fig. 1).

In Pervomaysk scheme (first and most powerful) hydraulic tube consists of heated chute and outlet tube which are connected tough with pump by traverse fixing and with lift-transportation mechanism (Fig. 2). System of MHD pump for delivery lead melt is meant for work stationary regime, is fastened to pot and is connected by flange with chute (Fig. 3).

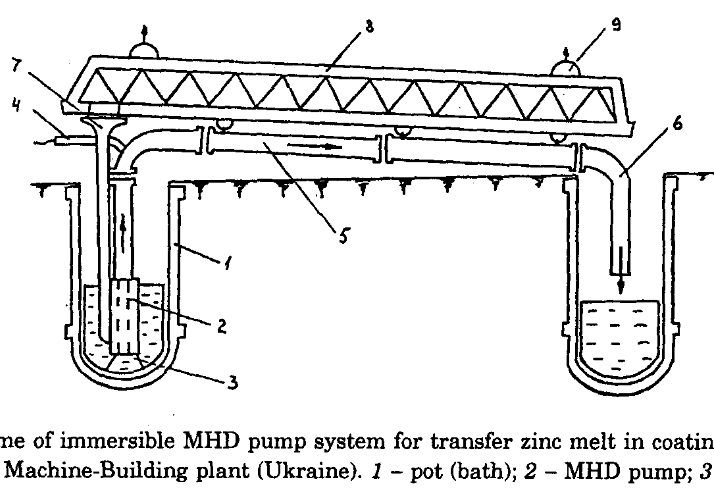


Fig. 2. Scheme of immersible MHD pump system for transfer zinc melt in coating workshop Pervomaysk Machine-Building plant (Ukraine). *1* – pot (bath); *2* – MHD pump; *3* – inlet; *4* – terminals; *5* – heated tray; *6* – outlet nozzle; *7* – fixing; *8* – traverse; *9* – lift-transportation mechanism.

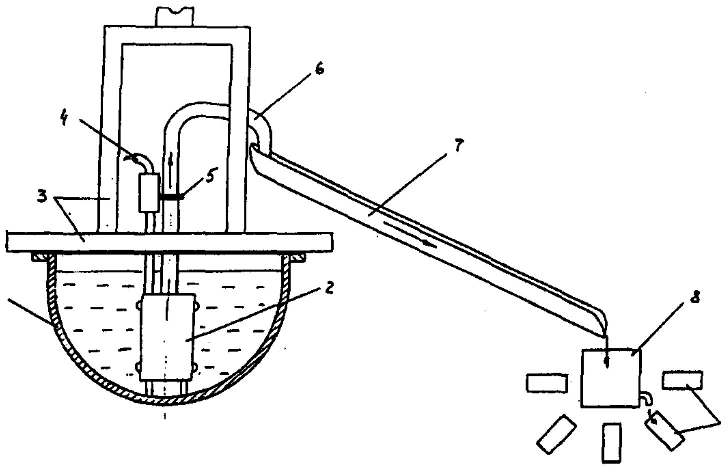


Fig. 3. Scheme of immersible MHD pump system for permanent delivery lead melt to batcher for plant "krzinc". *1* – pot (bath); *2* – MHD pump; *3* – frame for fastening the pump to pot; *4* – terminals; *5* – flange connection; *6* – chute; *7* – tray; *8* – batcher storage; *9* – moulds.

Common feature for above named systems is a construction of pump. It is flat-linear, immersible type, without external cooling, with vertical orientation. The construction of Cherepovets pump was developed by designer V. E. Strizhak. System consists of two inductors (MHD pump), pressure outlet, terminal box with cable pipes and netting for inlet of pump. Each inductor has laminated magnetic core, winding, casing. Laminated core is made from electrical sheet steel with coating working at temperature up to 650 C. Winding is is three-phase, double-layer, made from copper wire. Insulation is high-temperature (650 C) on base of mica. Casing is welded, is made from stainless steel.

In time of design of MHD pump they guess that main dimensions of pump are height of channel on liquid metal 2Δ, thickness of wall of channel Δ_l width of channel $2a$, active length of pump $2p\tau$, where τ is pole pitch, p – is number of pole pairs [1]. Taking in account different initial data (capacity, height of melt lift, physical characteristics of media and so on) and given current loading, keeping main technological devices, the choice of main dimensions comes to determination of parameters Δ, Δ_l, p.

From theory of electromagnetic induction pumps it is known [2], that ideal efficiency of pump (without taking in account hydraulic losses and electrical losses in inductors) is equal to

$$\eta_{id} = \frac{\Delta_S/\Delta\left(1-\Delta_S/\Delta\right)}{1+(\sigma_1\Delta_1)/(\sigma\Delta)-\Delta_S/\Delta}.$$

$\Delta_S = Q/8af\tau$ – constant for given capacity Q, frequency of current f and for parameters $2a$, τ, chosen according technological reasons; σ_1 – electrical conductance of channel wall; σ – electrical conductance of melt.

Maximum of ideal efficiency

$$\eta_{idm} = \left(1+\sqrt{\frac{\sigma_1\Delta_1}{\sigma\Delta}}\right)^{-2}$$

will be when $\Delta_m = \Delta_S + \sqrt{\sigma_1/\sigma\,\Delta_1\Delta_S}$.

Table 2

Main parameters	AMH-7	AMH-11AЦ	AMH-13Ц	AMH-14C
Pole pitch τ, m	0.167	0.167	0.167	0.167
Width of channel 2a, m	0.15	0.15	0.15	0.15
Liquid metal gap 2Δ, m	0.025	0.025	0.016	0.016
Thickness of channel wall Δ_1, m	0.01	0.0075	0.008	0.006
Material of channel walls	X18H10T	03X17H14M3	X18H10T	X18H10T
Material of casing	—"—	—"—	03X17H14M3	—"—
Full gap between inductors, m	0.046	0.0408	0.0328	0.0288
Number of poles 2p	8	5	4	8
Full length of inductor, m	1.5	1.0	0.8	1.5
Winding factor	5/6	5/6	5/6	5/6
Number of teeth in one inductor	107	71	59	107
Tooth pitch, mm	13.9	13.9	13.9	13.9
Width of slot, mm	8.9	8.9	8.9	8.9
Height of slot, mm	69	69	69	69
Height of back, mm	30	30	30	30

In variant of Cherepovets pump $\Delta_S = 5\cdot10^{-3}$ m; $\sigma_1\Delta_1/\sigma = 3.75\cdot10^{-3}$ m; $2\Delta_m = 1.85\cdot10^{-3}$ m; $\eta_{idm} = 0.287$.

If to take in account that losses in inductors and channel remove the maximum efficiency in side of greater liquid metal gaps, the value of $\eta_{idm} = 0.287$ for wall thickness $7.5\cdot10^{-3}$ m and gap $2\Delta = 25\cdot10^{-3}$ m is optimal.

Number of pole pairs is equal $2p = Ah/I^2$, where h – height of melt lift, I – phase current, A – constant determined by physical parameters of melt, given channel geometry, data of inductor winding. For Cherepovets pump variant value $A \cong 60\,000$ A/m, $2p = 5$ (number is whole).

Main dimensions of other systems of pumps were chosen the same way (see Table 2). Complicate conditions for pumps exploitation, high cost of materials, including high temperature insulation, demanded of the row theoretical and experimental investigations, connected with improving of calculation method, analysis of thermal and hydraulic regimes, searching of materials stable for corresponding melts and temperatures. The results of those investigations were given in detail in [3–7], now we will mention shortly some of them.

I. In result of preliminary tests of Pervomaysk MHD pump with pumping the melt from pot to the same pot it was found out that capacity of pump is in two times greater then calculation predicted.

For improving the calculation method such specific peculiarities of present pump were taken in account as:

– relatively thick channel walls;

– availability of large bulk of melt around the pump; external melt plays role of connecting buses. It decreases transversal end effect;

– heterogeneity of magnetic field along the width of channel and polyharmonic character of current loading distribution along the length of channel.

Account above named factors lets to obtain good concordance between calculation and experiment. In Fig. 4 is pointed nominal point according previous calculation (point A). Curve *2* was calculated according specified method for experimental distribution of magnetic field, curve *3* was calculated according specified method with use calculated distribution of magnetic field for

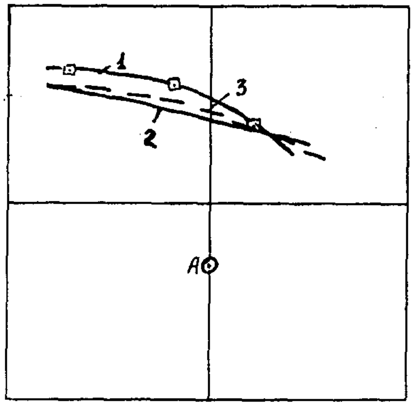


Fig. 4. Dependencies of pressure (head) on the capacity for Pervomaysk MHD pump. *1* – experiment; 2 – calculated according specified method for experimental distribution of magnetic field; 3 – calculated according specified method with use calculated distribution of magnetic field for presented current loading.

presented current loading. There is a good concordance between experimental curve *1* from one hand and curves *2* and *3* from another.

In base of modernized calculation method theoretical investigations underlie, developed by MHD Laboratory co-worker, Ph. D. S. Yu. Reutsky. This analysis, in particular published in [5–6], is unique. Method includes the solution of three-dimensional task about magnetic field distribution [6] and following approximation it by polyharmonic functions, includes determination of distributions current density, electromagnetic forces in liquid metal and energetic performances. Using of the method allowed to decrease by 1.5 times the dimensions of Cherepovets pump, by 2.5 times of Mariupol pump, to place in dimensions of Pervomaysk pump the pump for lead. It is led to decreasing of machines cost.

II. From consideration of heat regimes arousing when the pump suddenly drops to the melt, it was revealed the influence of such factors as preliminary warming-up, moment of turn-on of the voltage, velocity of immersion to the melt.

Above named regimes were described in [4], now we will give the main results. Immersion of cold inductor into melt lets to intensive taking away of heat from melt inside of channel up to hardening.

1. In particular, calculation made for parameters of Pervomaysk pump shows , that for "cold" pump immersed into liquid zinc, the liquid zinc inside channel becomes hard after 3.2 min and will melt again after 4.5 h only.

2. Intensity of taking away of heat from melt inside channel decreases if preliminary to warm up the pump.

3. Preliminary warming-up is established by open-circuit pump currents without melt in channel. In this case the channel walls owing to the eddy currents warm up considerable faster then inductors, reaching the melting-point (460 °C) when inductors remain still relatively cold (210–230 °C).

4. With increasing of winding current the velocity of warming-up increases. Thus, if the phase current is equal to 60% of nominal value, warming-up continues about 2 h, it is allowed for planned moving off of the pot. If the phase current is equal nominal value, channel warming-up proceeds practically adiabatic ally, reaching melt melting-point in 3 min. This regime is admissible in emergence situation, but it is extremely dangerous for channel integrity because the channel can melt,

III. In connection of choice of materials for immersible part of pump there were made investigations for corrosion stability of stainless austenite steels type X18H10T in zinc melt with temperature 450–500 °C and types 03X17H14M3, 316L (USA) in aluminum melt with temperature 765–780 °C, and some coating, protecting those steels [7].

Permeability P characterizing material taking away was determined according losses of unit mass:

$$P = 87.6\Delta m/\gamma St \text{ (mm / year)},$$

m – loss of mass in result of corrosion; g; γ – material density, g/cm^3; S – square of surface of unit, contacted with melt, cm^2; t – duration of test, h. Further some results of tests are listed.

1. In conditions of working hot zinc galvanizing pot with temperature of zinc melt 460 °C taking away of steel X18H10T was equal to 116.5–134 mm/year; but welded joints were in good condition and practically did not have a corrosion. Based on those results, resort of Pervomaysk pump we estimate as much as 425 h. Taking in account that one moving off pot melt has a duration about 1 h 15 min above named time is enough for 340 moving off procedures (usually 1 – 2 moving off per year are necessary).

2. Taking away of steels 03X17H14M3 and 316L (USA) in aluminum melt with temperature 760 – 780 °C is equal to 600 mm/year (non-hardened steel 03X17H14M3) and 140 mm/year (hardened steel 03X17H14M3); 160 mm/year (non-hardened steel 316L).

It is necessary to point that composition of steel 03X17H14M3 not completely corresponds to the standard (GOST 5632–72). Steel contains less nickel (10% instead 13–15% according GOST) and has a little titanium (less then 1%). According [9] if content of nickel is less then 10%, austenite status is unstable and in force of high temperature and inner tensions can transfer lightly to martensite status. We watched this phenomenon: pieces of steel became magnetic somewhere. Bringing the protecting coating decreases taking away the material , in particular in aluminum melt up to 6 mm/year.

In conclusion note, that use of MHD system let not only considerable to decrease the duration of working cycle and to decrease the losses of melt, but to change in the main the technology pot filling bimetal.

2. Dosed supply of liquid metal. MHD Laboratory has created two systems with MHD pump for dosage of rough gallium. Gallium is extracted from carburization tank and then dose of gallium is pumped in tank again with following sink of remained gallium as a ready product (Fig. 5). One of those systems was started up on Bauxitogorsk Alumina Plant, Russia (1979), second is meant for Pavlodar Aluminum Plant. Unit is manufactured, but did not redeemed by plant, yet.

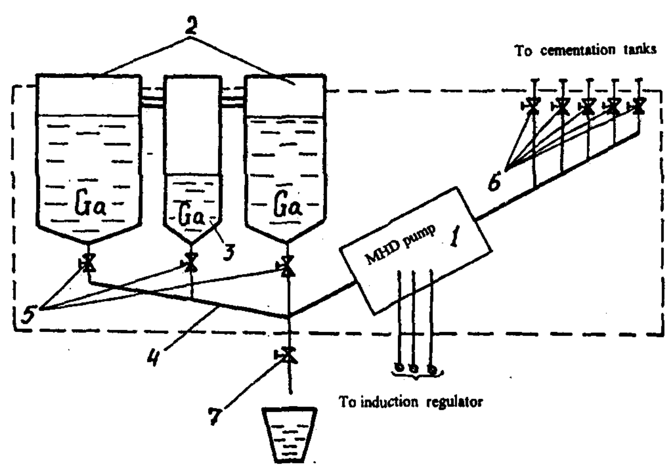


Fig. 5. Scheme of MHD pump system for dosage supply liquid rough gallium to carburization tanks. *1* – MHD pump; *2* – measured tanks; *3* – sink tank; *4* – pipes; *5* – clutches for connection of flowing part with tanks; *6* – clutches for connection of flowing part with carburization tanks; *7* – clutch for sink of ready production.

Two systems are similar, there is some construction difference, not in the main.

The main parameters of batcher for Pavlodar plant are: media-gallium with temperature up to 180 °C; doses – 30, 60 kg; height of lift gallium – 4 m; duration of metal transfer – 50 sec;

The use of unit decreases the losses of gallium, improves conditions of work, mechanizes the manual labor.

3. Casting of motor rotors by aluminum by method of adjusted pressure. In present time it is known two methods for rotors casting (potting): under high pressure and casting by gravity. Rotors casting by method of adjusting pressure uses the advantages of both methods. Adjusting of pressure is realized with use of MHD pump which is installed in metal way between furnace with melt and press form (Fig. 6).

Idea of method of adjusting pressure belongs to "UkrNiiLitMash" (Kharkiv, Ukraine). This enterprise developed experimental stand. MHD Laboratory developed and manufactured system of MHD pumps. System of MHD pumps has realize:

– supply of melt to press form;

– pressing after filling of press form;

– reverse of reminder of liquid metal;

– bar of metal way.

According pointed conditions system consist of:

1. MD pump, induction, thr.ee-phase, screw (spiral) channel;
2. Control board;
3. Standard adjustable voltage source.

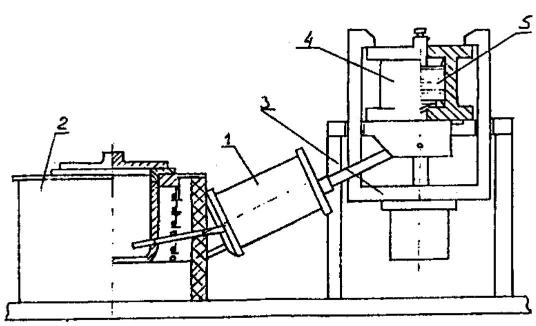
Pump is dismountable, channel is replaceable in exploitation process. Main construction units are:

– external inductor with rotating magnetic field. Magnetic core laminated from *permendure* – alloy on base cobalt, has high Curie point; winding is three-phase, made on base of high – temperature insulation developed by VNIIEIM, Moscow, Russia. Winding was steeped special high-temperature composition;

– internal inductor, made by magnetic core without winding;

– screw (spiral) channel which has inlet and outlet for hydraulic connection with reminded part of metal way; channel is made from stainless steel 3H943, which according literature data is stable in aluminum melt with temperature 780 °C;

– pump casing with terminals box.



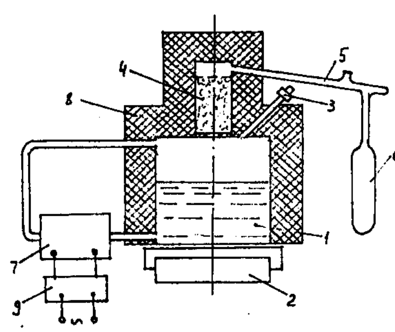


Fig. 6. Scheme of experimental stand for motor rotor potting. *1* – MHD pump; *2* – electric furnace; *3* – mechanism for press form locking; *4* – press form; *5* – laminated rotor.

Fig. 7. Scheme of unit for obtaining pure rubidium (cesium). Lovosersk ore mining and processing enterprise, Russia.

Main project system parameters:

1) casting regime: capacity – $0.9 \cdot 10^{-3}$ m^3/sec; head – $2.5 \cdot 10^5$ N/m^2 = = 2.5 atm; line voltage – 80 V; phase current – 40 A;

2) metal pressing regime: capacity – 0; maximum of head – 25 atm; line voltage – 140 V; phase current – 120 A (loading is short-term).

Pump was tested in regime idling. Experimental data is in good concordance with calculated data. Particularly, for calculated nominal regime values of current, voltage and induction in center of channel are equal 40 A, 80 V, 0.2 T correspondly. Experimental values are equal 40 A, 87 V, 0.19 T. Hot test is planned in nearest time.

4. MHD pumps in units for obtaining pure alkaline metals. In Fig. 7 is showed scheme of unit which is meant for obtaining of pure rubidium (cesium) from melt, coming from furnace origin ore. Unit was developed by E. P. Lokshin on Lovosersk ore mining and processing enterprise. Melt is placed in distiller *1* with volume 20 L made from stainless steel. Distiller is heated by electrical heater *2* and filled by melt through inlet *3*. Above of distiller so named deflegmator *4* is placed. It is a column filled by special metal shavings (chips). In top of deflegmator there is condensation pipe *5* and glass or metal vessel *6*, in which rubidium drops. Distiller and deflegmator are covered by thermal insulation *8*.

When melt reaches 380 – 400 °C it begins to boil, the steam goes through deflegmator, where cleans itself, then condenses in pipe *5* and gathers in vessel *6*.

For increase of efficiency of unit they decided to equip it by MHD pump *7* which picks up the melt from bottom part of distiller and transfer it to top (height is equal 250 mm). MHD Laboratory made in 1980 for unit single-phase alternating current high temperature (500°C) pump with flow rate 0.7 m^3/h, head 0.01 MPa. Pump has a series excitation. Power supply realizes by bucking transformer *9*. Use the pump provides increase the level of metal purity.

Systems of MHD pumps similar to described, for determined technical conditions can be developed , manufactured and started up by our enterprise.

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