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MECHANIC VIBRATIONS GENERATION SYSTEM AND EFFECT ON THE CASTING ALLOYS SOLIDIFICATION PROCESS

Crenguța Manuela PÎRVULESCU[1], Constantin BRATU[2]

În lucrare este analizată posibilitatea tratamentului materialelor metalice lichide şi cristalizarea acestora sub influența vibrațiilor mecanice. Pentru a demonstra existența efectului vibrațiilor mecanice am încercat evidețierea acestora prin rezolvarea a două probleme: 1- prin proiectarea şi execuția unei instalații pentru realizarea vibrațiilor mecanice, definite de anumiți parametri: frecvență, amplitudine accelerație, măsurate cu ajutorul unor aparate (dispozitiv electronic de comandă şi control), 2- prin modificarea structurii cristaline a materialelor metalice, prin turnarea în cochilă metalică a unor probe. Testele au fost făcute pe aliaje aluminiu-siliciu turnabile sub influența vibrațiilor şi turnare gravitațională clasică, pentru a avea o probă martor.

The paper discusses the possibility to apply a treatment to the liquid metallic materials and their crystallization under the influence of mechanical vibrations. To demonstrate the existence of the effect of the mechanic vibrations we tried to make them evident by solving two problems: 1 - by designing and implementing a facility to achieve mechanical vibrations, defined by certain parameters: frequency, amplitude acceleration, measured by using some instruments (checking and control electronic device), 2 - by changing the crystalline structure of metallic materials by chill casting of metal samples. Tests were made on aluminium-silicon alloy castings under the influence of vibrations and classic gravity casting, to obtain a blank.

Keywords: vibrations, Al-Si alloys, metal mould casting

1. Introduction

The totality of metals and alloys begin to work by a very important operation, that of solidification. Solidification is the operation that gives shape and structure.

Currently the solidification technique has experienced a rapid development. Because of progresses made as yet the castings are used in high security parts in the aero-spatial industry, the automotive, chemical and metallurgical equipment.

[1]. PhD student, Teacher, Colegiul Tehnic „Media” of Bucharest, Romania, e-mail: pcrenguta@gmail.com

[2] Prof., Faculty of Applied Chemistry and Materials Science, University POLITEHNICA of Bucharest, Romania

The theoretical phenomena of alloys solidification address the problem of solid and liquid state. Further on the microscopic aspects of solidification, the mechanisms of columnar and echiaxial growth, solid fraction evolution, the problem of alloys solidification at the scale of dendrites and casting grains, the segregation in the cast products, cast-scale contractions, stresses, microporosities and internal cracks are described.

The physical processes of alloys crystallization and solidification, investigation of alloys crystallization conditions by applying mechanical oscillations, vibration influence over the mass transfer in alloys during their solidification, vibration influence over the thermo-physical processes in solidification are described in the paper.

The basic idea highlighted in the paper is that the process of crystallization and solidification in the gravitational field can no longer provide all the structure, physical and chemical homogeneity of the cast alloys to meet the current requirements of industry. For this reason it is necessary to conduct these processes in a controlled manner. In this line the vibration (of all types known) applied to the alloy during solidification is one of the technological solutions that are easy to reach in many foundries. This procedure leads to the achievement of physical and mechanical properties having a value substantially higher versus the conventional casting conditions.

2. Experimentel design of vibrating installation (IVAEP)

The manufacturing, commissioning and working conditions allowed the use of simplifying assumptions, leading to simple mechanical models, the results meeting the design calculations. These assumptions were:

1) The vibrating installation is a complete centred system, i.e. the resultants of the disruptive, elastic and dissipative forces pass through the system mass centre. The assumption is made for the vibrating movement in both vertical and horizontal plane.

2) The electric motors have enough power so that the motor- vibrant installation interaction (mass) is negligible. It results that the installation operation under a stationary circumstance is done with constant angular velocity.

3) All elastic elements (cylindrical helical springs with round section) belong to the same group. They have similar characteristics, i.e. the differences between the elastic characteristics are small enough that they can be neglected. Elastic elements mass effect is neglected.

In this paper the emphasis is put on determining the dynamic parameters by physical and mathematical modelling, depending on the parameters that can be determined experimentally. Also, some mathematical methods adapted by the author are presented, which allowed automated calculation of the vibration parameters.

From the constructive point of view, the component parts of the actual model, are chosen at the designing stage with higher stiffness to prevent the own vibration of the bar or membrane type. We used metallic elements (cylindrical helical springs) to produce and maintain the vibrating movement and rubber elements to dissipate the energy with the purpose of antivibratory insulation.

Harmonic disturbing forces (necessary to produce harmonic vibrations) in the plant are produced in two planes:

● vertically, with a pneumatically actuated small piston operated by an electric machinery;

● horizontally, by an electric machinery with a cam-type system.

The moulding plant that uses low frequency vibration (IVAEP) is used during the crystallization and solidification of liquid non-ferrous metals, resins, etc. to improve their physic-chemical characteristics.

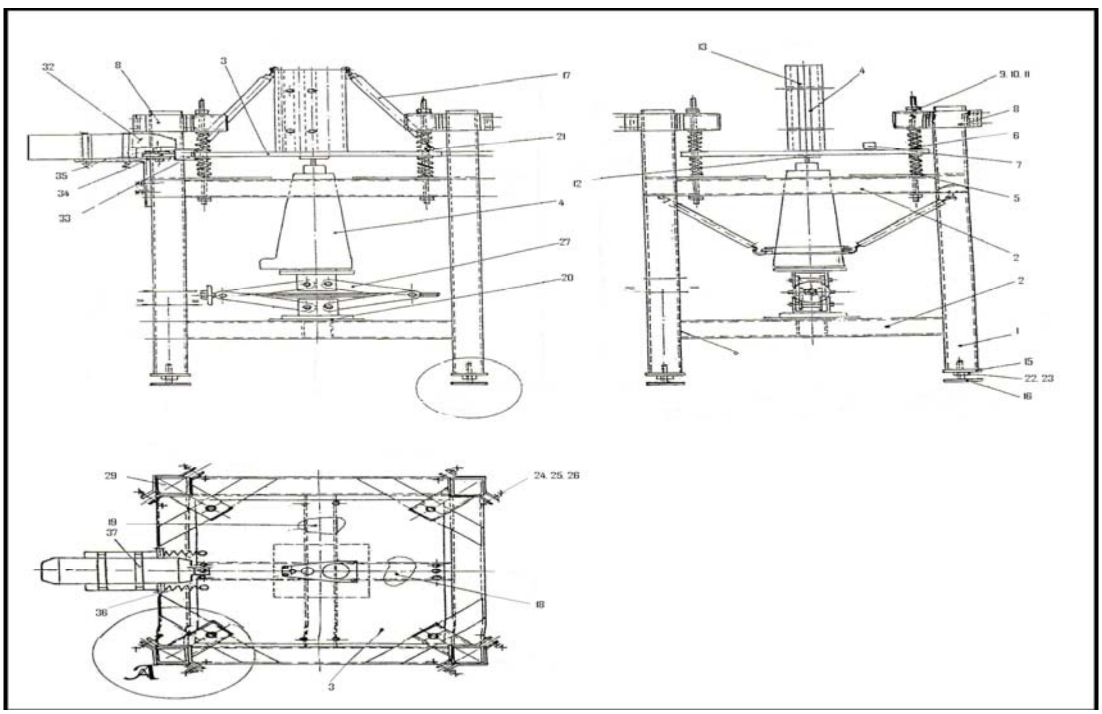

Fig.1 Vibration installation lay-out

The main components consist of a chassis (1, 2), a rectangular device (27) for positioning and locking, a vibrant table (3), a vertical vibration generator (4) of 1-75 Hz frequency, 0.8mm amplitude and a system for their adjustment (17, 21, 27), a horizontal vibration generator (32), a cam mechanism (34), the elastic system (6), the piezoelectric accelerometer (7), a rigid console (8) for fixing and locking the elastic system, interchangeable dies (9, 13), a horizontal clamping and locking device(35), a horizontal (33) and vertical (12) percussion device, which produce vibrations by means of the two vibration generators, as shown in Fig. 1.

Table 1 shows the values of the response acceleration, speed and amplitudes for the working frequencies. The effective value (RMS) for the entire duration of recording, the effective value (RMS) during the pulse and average values of response acceleration maximums are shown.

Table 1

Values of the acceleration, velocity and response amplitude for various working frequencies

Frequency (Hz)		17	28.8	33.24	41.82	57.45	70.32	75
Acc (m/s^2)	RMS	140	237.2	273.8	344.45	473.19	579.26	617.74
Velocity (m/s)	RMS	0.0091	0.0151	0.0171	0.0384	0.0472	0.0817	0.0871
Amplitude (m)	RMS	0.0001	0.0003	0.0003	0.0004	0.0006	0.0007	0.0008

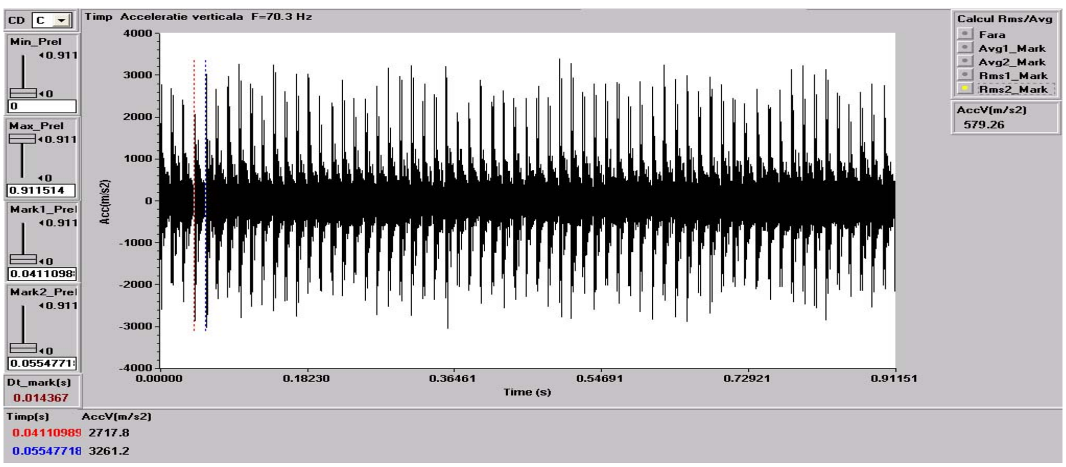

Fig. 2. Installation response acceleration for excitation with percution at 70.32 Hz

The entire system is controlled by an electronic control and tuning unit (UECR) made of a power supply block, a control block, an acceleration regulator block, a measuring block made of signal amplifiers that process signals from the two accelerometers and the measured values are displayed on two displays as shown in Fig. 3 and Fig. 4.

Fig. 3. The front panel of the electronic control and tuning unit

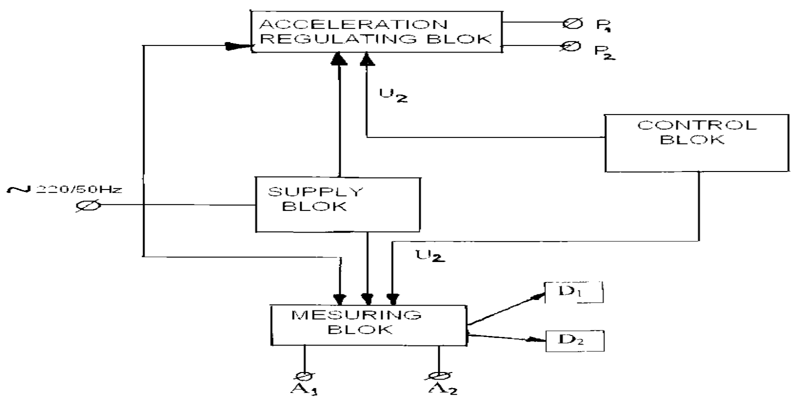

Fig. 4. Block diagram of the electronic control and adjustment unit

2.1. Calculation of the dynamic suspension and displacement amplitude

The dynamic suspension (6) is an elastic system by means of which the signals (vibrations) generated by the vibrations source can be sent to the subject of this vibrant table.

The elastic system is made of cylindrical helical springs of various sizes attached by means of some cups by using screws and nuts. Their assembly can be made of four or eight pieces each, mounted in parallel, being limited (locked) at the top by means of some devices.

The parameters calculation, version 1

$d = 4.6$ [mm], $D_e = 39.2$ [mm], $D_i = 30$ [mm], $D_m = 34.6$ [mm],

$n = 5$ active turns, $n_t = 7$ total turns, $L_s = 66$ [mm].

1) Calculation of relevant spring deflection force F = 75 N:

$$f = 8 \cdot F \frac{D_m^3}{G \cdot d^4} \cdot n = 8 \cdot 75 \frac{34.6^3}{8.1 \cdot 10^4 \cdot 4.6^4} \cdot 5 = 3.43 mm = 3.43 \cdot 10^{-3} \text{ [m]}$$

2) Maximum deflection of the spring in terms of resistance, τ_a = 660 N/mm^2

$$f_{\max} = \frac{\pi \cdot D_m^2 \cdot \tau_a \cdot n}{G \cdot d} = \frac{\pi \cdot 34.6^2 \cdot 660 \cdot 5}{8.1 \cdot 10^4 \cdot 4.6} = 33.3\,mm = 333 \cdot 10^{-3}\ [\text{m}]$$

3) Fuly compressed spring deflection:

$$f_{bl} = 66 - (7 \cdot 4.60) = 33.8\text{mm} = 33.8 \cdot 10^{-3}\ [\text{m}].$$

4) Calculation of the spring rigidity k_1 and of the 4 springs K;

$$k_1 = \frac{F}{f} = \frac{75}{3.43 \cdot 10^{-3}} = 21.86 \cdot 10^3\ [\text{N/m}]$$

$$K = 4 \cdot k_1 = 4 \cdot 21.86 \cdot 10^3 = 87.46 \cdot 10^3\ [\text{N/m}]$$

5) Calculation of the own pulsation p:

$$p = \sqrt{\frac{K}{m}} = \sqrt{\frac{87.46 \cdot 10^3}{30}} = 54\,[\text{rad/s}]$$

6) Calculation of the own oscillations frequency:

$$f_0 = \frac{p}{2 \cdot \pi} = \frac{54}{2 \cdot \pi} = 8.6\,[\text{Hz}]$$

7) Own vibration period of the vibrant table:

$$T = \frac{2 \cdot \pi}{p} = \frac{2 \cdot \pi}{54} = 0.1163\,[\text{s}]$$

8) Calculation of the own acceleration for: $x_0 = f = 3.43 \cdot 10^{-3}$ [m]:

$$a = x_0 \cdot p^2 = 3.43 \cdot 10^{-3} \cdot 54^2 = 10\ [\text{m/s}^2]$$

9) Calculation of the own frequency of the spring (undergone by the spring):

$$f_0^{'} = 3.63 \cdot 10^5 \frac{d}{n \cdot D_m^2} = 3.63 \cdot 10^5 \frac{4.6}{5 \cdot 34.6^2} = 279\ [\text{Hz}]$$

The parameters calculation version 2

d = 4.2 [mm], D_e = 36 [mm], D_i = 27.6 [mm],
D_m = 31.8 [mm], n = 4 active turns, n = 6 total turns, L_s = 50 [mm].

1) Calculation of relevant spring deflection force F = 75 N:

$$f = 8 \cdot F \frac{D_m^3}{G \cdot d^4} \cdot n = 8 \cdot 75 \cdot \frac{31.8^3}{8.1 \cdot 10^4 \cdot 4.2^4} \cdot 4 = 3.06\,mm = 3.06 \cdot 10^{-3}\ [\text{m}]$$

2) Maximum deflection of the spring in terms of resistance, τ_a = 660 N/mm2

$$f_{\max} = \frac{\pi \cdot D_m^2 \cdot \tau_a \cdot n}{G \cdot d} = \frac{\pi \cdot 31.8^2 \cdot 660 \cdot 4}{8.1 \cdot 10^4 \cdot 4.2} = 24.6\,mm = 24.6 \cdot 10^{-3}\ [\text{m}]$$

3) Fuly compressed spring deflection:

$$F_{bl} = 50 - (6 \cdot 4.2) = 24.8\text{ mm} = 24.8 \cdot 10^{-3}\ [\text{m}]$$

4) Calculation of the spring rigidity k_1 and of the 4 springs K:

$$k_1 = \frac{F}{f} = \frac{75}{3.06 \cdot 10^{-3}} = 24.5 \cdot 10^3 \ [N/m]$$

$$K = 4 \cdot k_1 = 4 \cdot 24.5 \cdot 10^3 = 98 \cdot 10^3 \ [N7m]$$

5) Calculation of the own pulsation:

$$p = \sqrt{\frac{K}{m}} = \sqrt{\frac{98 \cdot 10^3}{30}} = \sqrt{32.6 \cdot 10^2} = 57.09 \ [rad/s]$$

6) Calculation of the own oscillations frequency:

$$f_0 = \frac{p}{2 \cdot \pi} = \frac{57,09}{2 \cdot \pi} = 9,09 \ [Hz]$$

7) Own vibration period of the vibrant table:

$$T = \frac{2 \cdot \pi}{p} = \frac{1}{f} = \frac{2 \cdot \pi}{57} = 0.11 \ [s]$$

8) Calculation of the own acceleration for: $x_0 = f = 3.06 \cdot 10^{-3}$ [m]:

$$a = x_0 \cdot p^2 = 3.06 \cdot 10^{-3} \cdot 5.7092 = 9.97 \ [m/s^2]$$

9) Calculation of the own frequency of the spring:

$$f_0^{'} = 3.63 \cdot 10^5 \frac{d}{n \cdot D_m^2} = 3.63 \cdot 10^5 \frac{4.2}{4 \cdot 31.8^2} = 376 \ [Hz]$$

Calculation of the displacement amplitude under the influence of the perturbating force in the variant of spring assembly variant 1 and variant 2

Calculation parameters of:

- spring constant (k_5) for variant 1: $k_5 = 21.85 \cdot 10^3$ [N/m];
- spring constant (k_6) for variant 2: $k_6 = 24.5 \cdot 10^3$ [N/m];
- constant of the unit (K_0) of the 8 springs variant 1 + 2:

$$K_{4.5} = 4 \cdot k_5 = 4 \cdot 21.86 \cdot 10^3 = 87.46 \cdot 10^3 \ [N/m];$$

$$K_{4.6} = 4 \cdot k_6 = 4 \cdot 24.5 \cdot 10^3 = 98 \cdot 10^3 \ [N/m];$$

$$K_0 = K_{4.5} + K_{4.6} = 87.46 \cdot 10^3 + 98 \cdot 10^3 = 185.46 \cdot 10^3 [N/m];$$

- own pulsation (p) of the unit of the 8 springs variant v1 + v2:

$$P = \sqrt{\frac{k}{m}} = \sqrt{\frac{185.46 \cdot 10^3}{30}} = 78.6 \ [rad/s];$$

- value of the mass to vibrate: m = 30 [Kg];
- value of the maximum perturbating force: $F_o = 5040$ [N];
- pulsation of the maximum perturbating force: $\omega = 475$ [rad/s];
- calculation of the static deflection under the perturbating force action:

$$x_s = \frac{F_0}{k} = \frac{5040}{185.46 \cdot 10^3} = 0.027 \ [m];$$

- calculation of the amplification factor:

$$A_1 = \frac{1}{1-\frac{\omega^2}{p^2}} = \frac{1}{1-\frac{475^2}{78.6^2}} = 0.02815$$

- calculation of the vibration amplitude value for variant v1 + v2:

$$X_0 = x_s \cdot A_1 = 0.027 \cdot 0.02815 = 0.00076\ [m] = 0.76\ [mm]$$

From the tests performed to calibrate the installation as shown in the diagram in Fig. 5, at a frequency of f = 70.32 Hz, the displacement amplitude value was $X_0 = 0.00079208$ [m].

By comparing the two values obtained by mathematical calculation $X_0 = 0.00076$ [m] and experimentally $X_0 = 0.00079$ [m] it results that they have very close values which means that both the designing method used and the practical construction of the installation have been properly conceived and achieved.

By the tests performed it has been established that the values of the frequency and amplitude are constant, reproducible throughout the duration of the experiments, which imposes it as a method to be used in the practice of casting the liquid alloys of the nonferrous metals under the vibrations influence in order to obtain the cast parts and ingots.

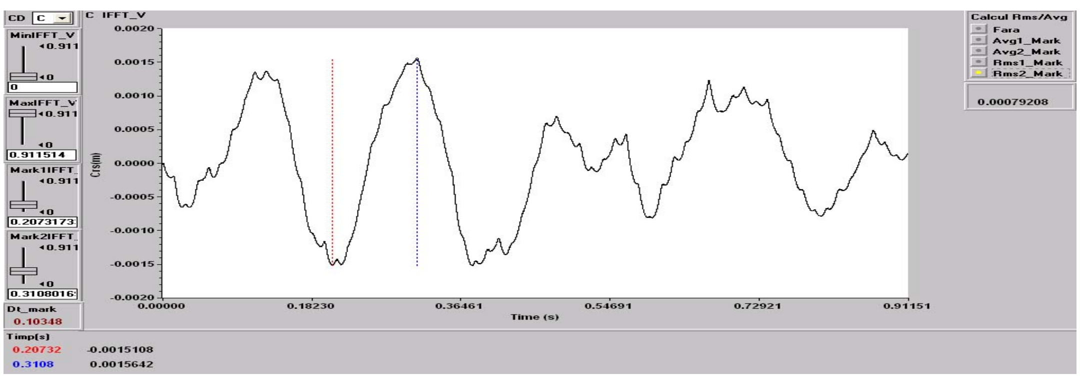

Fig. 5. Response displacement of the installation at the frequency 70.32 Hz

3. Results and Discussion

The cast samples have been identified in the following way:

- samples cast under the gravity influence, of the O witness type: O1, O2, O3 etc;
- samples vibrated after having been cast in the mould until they are solidified, of the V type: V1, V2, V3, V4, V5 on the vibrating installation;
- samples cast under the gravity influence by vibrating the metallic melted fluid in the cast vessel of the O' type: O'1, O'2, O'3, etc;

- samples of alloy vibrated in the cast vessel and mould vibrating after the casting took place until they get solidified on the vibrating installation (IVAEP) of the VV type: VV1, VV2, VV3, VV4, VV5 etc;

Out of the multitude of samples that have been processed, the most representative have been kept; the cast samples identification, dimensions, parameters, way of crystallization solidification are shown in table 2.

Table 2

Samples used in casting

Item No.	Sample type	Sample Diameter [mm]	Sample height [mm]	Vibr. Freq. [Hz]	Way of casting solidification
1	O1	10	240	-	sample cast of unvibrated alloy, solidified in air
2	O2	20	240	-	sample cast of unvibrated alloy, solidified in air
3	O3	40	240	-	sample cast of unvibrated alloy, solidified in air
4	O/1	10	240	50	sample cast of alloy vibrated in the cast vessel, solidified in air (vessel vibration)
5	O/2	20	240	50	sample cast of alloy vibrated in the cast vessel, solidified in air (vessel vibration)
6	O/3	40	240	50	sample cast of alloy vibrated in the cast vessel, solidified in air (vessel vibration)
7	V1	10	240	50	sample cast of unvibrated alloy, solidified
8	V 2	20	240	50	sample cast of unvibrated alloy, solidified under the vibrations influence (mould vibration)
9	V3	30	240	50	sample cast of unvibrated alloy, solidified under the vibrations influence (mould vibration)
10	V4	40	240	50	sample cast of unvibrated alloy, solidified under the vibrations influence (mould vibration)
11	V5	50	240	50	sample cast of unvibrated alloy, solidified under the vibrations influence (mould vibration)
12	VV1	10	240	50	sample cast of alloy vibrated in the cast vessel, solidified under the vibrations influence (mould vibration)
13	VV2	20	240	50	sample cast of alloy vibrated in the cast vessel, solidified under the vibrations influence (mould vibration)
14	VV3	30	240	50	sample cast of alloy vibrated in the cast vessel, solidified under the vibrations influence (mould vibration)
15	VV4	40	240	50	sample cast of alloy vibrated in the cast vessel, solidified under the vibrations influence (mould vibration)
16	VV5	50	240	50	sample cast of alloy vibrated in the cast vessel, solidified under the vibrations influence (mould vibration)

Obtaining a compact metallic material is ensured if the speed v at which the alloy penetrates in the capillary channels of the biphasic area is equal to the contraction speed v_{contr}:

$$v_{contr} = \alpha \cdot m \cdot R \ \ [m/s] \tag{3}$$

where: α - alloy contraction coefficient at solidification;

m - relation between the liquid and solid phases volume in the biphasic area and the volume of this area;

R - solid phase occurrence speed [m/s].

The mechanic vibrations action leads to shrinkage hole depth decrease, and it gets round at its bottom.

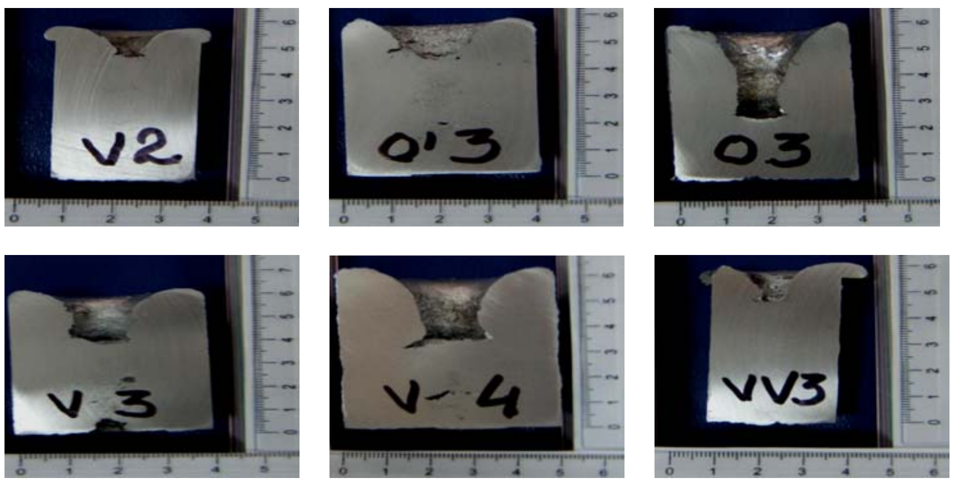

Fig. 6. Examples of shrinkage hole in cross-section

Table 3

Solidification contraction of various diameters of the ingots cast of AlSi12.5 Mg0.25

Item No.	Sample	Diameter [mm]	H [cm]	Sample Vol. [cm^3]	Retassure Vol. [cm^3]	Contraction at solidification C [%]
R1	O2	20	24	75.36	2	2.65
R2	O3	40	24	301.44	9.5	3
R3	O′3	40	24	301.44	6.5	2.15
R4	V3	30	24	169.56	2.2	1.3
R5	V4	40	24	301.44	6.5	2
R6	V5	50	24	471	10.0	2.12
R7	VV3	30	24	169.56	2.4	1.41
R8	VV4	40	24	301.44	6.4	2.16
R9	VV5	50	24	471	12.0	2.54

It can be noticed that the unvibrated samples R1, R2 (O2, O3) have the highest contraction, starting to get lower at the degassed ones R3 (O/), the vibrated R4, R5, R6 (V2, V3, V4) continuing with the degassed and vibrated ones R7, R8, R9 (VV3, VV4, VV5).

Under the mechanic vibrations influence the micro shrinkage hole overall volume gets smaller and the macro shrinkage hole gets concentrated at the top, large opening angle ($\omega > 120^0$) and penetration small depth, thus decreasing the liquid alloy volume for the useless (redundant) metal, phenomena that can be explained if it is considered that the alloy solidification takes place according to the following mechanism: controlled conducting the processes of formation and compacting of the equiaxial structure with small-broken crystals show the best physico-mechanical characteristics, displayed in table 4. It can be noticed that all the vibrated samples have values much higher versus the unvibrated ones.

Table 4

Samples values at the tearing, flowing, elongation, recking, hardness for the alloy AlSi12.5Mg0.25

Item No.	Sam-ple type	R_m [MPa]	$R_{p0,2}$ [MPa]	A_u [%]	Z [%]	HB [MPa]	Remarks
R1	O1	170	102	3.5	2	87.5	Unprocessed sample
R2	O2	176	101	3	2.04	88.6	0.5 mm inclusions at the break
R3	O3	175	103	3.2	2.2	87.3	
R4	O'1	185	111	4.2	5.8	89.3	
R5	O'2	93.8	-	-	-	-	Fault in the structure, hollows with 1.5 mm diameter
R6	O'3	186	112	5	-	90.6	
R7	V1	295	162	4.4	3	105	
R8	V2	296	162	4	2.7	104.3	
R9	V3	295	160	3.9	2.7	106.3	
R10	V4	294	170	3.9	-	103.1	
R11	V5	294	165			103.2	
R12	VV1	150	-	-	-	-	Fault in the structure
R13	VV2	295	147	5.6	3	99.3	
R14	VV3	294	145	4.2	1.5	98.6	
R15	VV4	290	150	2.1	2.1	97.2	
R16	VV5	285	151	4	2.8	97.3	Turned on lathe diameter from the 50 mm diameter, sample in the thermal axle

In table 5 we show comparatively the composition and mechanical characteristics of the main alloys based on aluminium-silicone for cast parts (variation limits) in the classic variant: (static casting) and various modes of mechanically vibrating the liquid alloy.

Table 5

Aluminium alloy mechanical characteristics standardized by comparison with the mechanically vibrated ones

Compo-sition	Casting procedure	Mechanical characteristics obtained by mechanic vibration				Main standardized mechanical characteristics			
		Rm [MPa]	$R_{p0,2}$ [MPa]	δ %	HB [MPa]	Rm [MPa]	$R_{p0,2}$ %	δ %	HB [MPa]
AlSi (6-18Si)	Mould	-	-	-	-	160	70	2...6	50
	R8.V2	296	167	4	104.4	-	-	-	-
AlSiMg Si12.5 Mg0.25 Mn0.2	Mould R2.02	233	186	3	88.6	200-220	110-121	2...4	60
	R4.O'1	285	213	4.2	89.3				
	R9.V3	295	162	3.9	103.3				
	R3.VV3	295	147	1.5	99.3				
	R15.VV3	290	150	2.1	99.3				

4. Conclusions

All the bibliographic sources that deal with the metallic meltings treatment with mechanic, ultrasonic, electromechanical vibrations, compared to other classic methods (with foundry agents, under vacuum, by gas bubbling, under pressure, etc.) highlight the fact that this treatment has a remarkable influence over the structure obtained after the solidification and over the mechanical characteristics, with respect of their improvement.

The contributions brought about by dealing with this theme and by personal researches performed are the following:

We have shown the influence of the mechanic vibrations on the metallic meltimelts.

1. By further energy infusion in the system, a modification of the system structure is obtained.
2. The treatment with mechanic vibrations aplied in the liquid phase and during the alloys solidification leads to the final structure improvement and to the improvement of the cast parts mechanic characteristics
3. The treatment with mechanic vibrations makes easier the formation of the gaseous inclusions and their removal from the alloy, a high de-gassing of the alloy is obtained.
4. By aplying the mechanic vibrations the inclusions removal from the alloy gets easier and more accelerated.
5. By treating the metalic melts during the solidification process with mechanic vibrations, the micro shrinkage hole can be largely removed and the macro shrinkage hole can be brought to a concentrated state.
6. By aplying the mechanic vibrations the internal strains and their consequences can be lowered.

The practical research performed, combined with some researches based upon the bibliography consisted in the following:

1. Researches and surveys concerning how to produce mechanic vibrations and transmit them to the metallic melting by means of a vibrating table.

2. Designing and construction of a vibrations producing installation with electro pneumatic actuation.

3. Researches concerning the physic al peculiarities of the procedure of handling the liquid alloys cast in metallic shapes by vibrations.

4. Experimental determinations by means of the density and hardness test.

5. Determinations concerning the cast parts mechanic characteristics.

6. Researches concerning the low frequency vibrations influence over the Al-Si alloys, especially AlSiMg.

The practical researches have been conducted on an installation that was patented and registered at O.S.I.M. under the number A/00372; it is going to be published in the official bulletin of Industrial Property, Inventions Section number 11 from 2010 according to art. 23 para.1.

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