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REDESIGN OF HYDRAULIC CIRCUIT TO IMPROVE QUALITY IN HIGH PRESSURE ALUMINUM DIE CASTING MACHINE

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Abstract

Pressure/velocity remains as main factors in a high pressure die casting machine to produce intricate components from the die. Rejection analysis was carried out in a die casting machine used in producing Aluminum components with a higher rejection rate. Three modifications have been carried out in the basic hydraulic design of the machine to increase the efficiency and in turn reduce the rejection of the components. The three modifications include (i) addition of nitrogen bottle to the system design (ii) Reducing the passage diameter of the Intensifier output (iii) Regeneration of Intensifier output. The first modification resulted with increase in pressure and the second with increase in velocity and finally the third one with optimum increase in both pressure and velocity. This has resulted in the improvement of machine efficiency thereby reducing the overall rejection of the components with intricate design.

Keywords: Nitrogen bottle, Accumulator, Intensifier, Pressure, Velocity.

1. Introduction

Pressure die casting machine (*m*/*c*) is the process which is used to produce accurate castings of automobile parts and other mechanical components [1]. Aluminum, zinc, copper are some of the materials with which die casting process can be carried out successfully. The type of products manufactured from these machines mainly range between industrial goods to automobile (2 wheelers and 4 wheelers) that includes sprockets, starter motor assembly, etc. [2, 3]. Production of casting depends on the parameters like velocity, pressure and temperature which are involved with the system [4].

Nomenclatures

D1	Intensifier input diameter, m
D2	Intensifier output diameter, m
P1	Intensifier input pressure, N/m^2
P2	Intensifier output pressure , N/m^2
Q1	Intensifier input discharge, m^3/s
Q2	Intensifier output discharge, m^3/s
x	Feedback flow, LPM
y	Feedback pressure , kg/cm^2

Among these, pressure is considered to be the primary parameter in the improvement of efficiency/quality of the product [5, 6]. Addition of nitrogen bottle (N.B) along with the accumulator has contributed to increase in pressure [7] which has also favoured in improving the efficiency [8]. Possibilities of changing a new intensifier/ accumulator in order to increase the pressure are all possible but cost constraint is an important aspect which is to be considered commercially. So modification in the existing design has proved efficient with experiments [9].

The effect of the secondary parameter, i.e., velocity has also been reported in various literature studies. Two accumulators have been used in order to increase the velocity [9-11], related to which works on increase in velocity and faster solidification has been carried out in terms of accumulator design modifications leading to finished products with less number of defects.

Certain modifications have also been carried out that has subsequent control over both pressure and velocity, one such design is back to back intensifier model [12]. Regeneration of Intensifier unit is another vital method implemented for efficiency improvement [13]. Intensifier unit replacement is done with a high pressure and low pressure pumps [14].

Direct implementation is not practically possible without simulation in today's competitive world, So overview has been made on the software which includes both Hydraulics and PLC that has been introduced by Famic technologies [15], experimented and practically used by Swider et al. [16] in PLC and by Cheng and Steven [17] in hydraulics. Timer is one important aspect that helps automation in PLC [18] and its application in hydraulic system is all about automation/ Mechatronics [19-22]. Automation studio, Vickers hydraulics, Festo Fluid sym, etc., are some of the leading software's used by experts and researchers in this area.

From the literature stated above, it becomes evident that attempts has been made either to improve the efficiency of the die casting machine either in the design stage or by adding new accessories ending up with high expense and sometimes with no improvement in efficiency. Therefore in this work, the existing design parameters are modified to the requirement and simulated to visualize the improvement in efficiency.

2. Experimental Work

Components related to textile thread extracting and automobile parts are being produced in a high pressure die casting machine with a capacity of 120T locking force. Some detailed information on the type of the die casting machine selected are shown in Table 1.

Table 1. Some Detailed Information on the Type of the Die Casting Machine.

Information	Value
Nitrogen pressure	68.64 bar
Intensifier pressure	294 bar
Accumulator pressure	107.8 bar
Intensification pressure holding time	min. 2 seconds
T1 plunger return after cycle started	8 seconds
T2 die holding time	6 seconds
T3 ejection forward	4 seconds
T3 ejection return	4 second
Metal temperature	650±20 °C
Plunger rod length	345-355 mm
Short sleeve length	180 -190 mm
Ladle length	70-90 mm
Plunger limit switch position	100±10 mm
Die pre heating	140±15 mm

All the parameters that contribute to the rejection like machine setting, metal composition, temperature etc. were ensured for achieving the required quantity. Then the machine design was studied. Production and rejection level were studied for a period of 3 months before and after the implementation of design modification. In the high pressure die casting, three phases are observed to be common [23] and has been studied. Three types of design modifications have been carried out in this work which includes (i) Addition of a nitrogen bottle (ii) Increasing the intensifier output passage and (iii) Regeneration of intensifier output. Automation studio, analysis software is used for carrying out the modification in the existing hydraulic circuit of the machine.

Few of the requirements that are not available in this software were designed separately and attached with the circuit for possible simulation. Those requirements are nitrogen bottle design and intensifier unit design.

3. Results and Discussions

3.1. Production and rejection analysis

Table 2 gives the data related to the production and rejection level for a period of 3 months before the implementation of design modification. It can be noted that the rejection level lies in the range of 11 to 13% on an average. The type of rejections and reasons for the same are as follows:

Blow holes- Caused due to earlier solidification, and the solid material cannot absorb the dissolved gas leading to blow holes/ gas pores.

Formation of oxides- Aluminium oxide is formed on the reaction of atmospheric oxygen over the molten metal the leading to reduction in strength of the casting due to improper solidification.

Burr- Formation of the burr is mainly because of the uneven machine clamping force and poor fit of the molding tool. Also the Aluminum melt temperature should be at the correct limits to avoid unexpected burrs.

Surface defects-- This occurs when the metal begins to solidify with incorrect temperature maintained for the metal leading to rejection.

Table 2. Production and Rejection before Design Modification.

	Constraints				1st Month				2nd Month				3rd Month			
Sl.no	Item name	End product	Alloy Grade	Weight/ piece (gms)	Production Quantity (nos)	Good Casting (nos)	Rejection Casting (nos)	Rejection %	Production Quantity (nos)	Good Casting(nos)	Rejection Casting (nos)	Rejection %	Production Quantity (nos)	Good Casting (nos)	Rejection Casting (nos)	Rejection %
1	Main body	Air Horn	LM-24	100	668	585	83	12.42	845	739	106	12.54	274	242	32	11.67
2	Ring Holder (Dia 40)	Textile Thread Extracting Machine	LM-24	28	1123	995	128	11.39	485	423	62	12.78	753	680	73	9.69
3	Ring Holder (Dia 42)	Textile Thread Extracting Machine	LM-24	32	2246	1995	251	11.17	2000	1802	198	9.9	1393	1250	143	10.26
4	Bearing Saddle	Textile Thread Extracting Machine	AD C 12	25	3032	2637	395	13.02	1556	1391	165	10.6	930	817	113	12.15
5	Tension Roller	Textile Thread Extracting Machine	LM-24	22	7309	6512	797	11	9012	8015	997	11.06	5865	5089	776	13.23

3.2. Effect of addition of a nitrogen bottle to the design

The hydraulic circuit installed in the die casting machine had one nitrogen bottle which was shared for both the accumulator and intensifier units. The performance of the system was not up to the mark and hence it was decided to modify the circuit by incorporating the additional nitrogen bottle as shown in Fig. 1. But due to some technical limitation in the direct addition of nitrogen bottle, it was replaced with a setup consisting of an accumulator and a pressure relief valve. The pressure relief valve is set with a maximum pressure of 90 bars and the accumulator is pre charged with the pressure required to be produced in the nitrogen bottle, i.e., 70 bars. Hence forth in this article this setup will be referred as nitrogen bottle.

The design of nitrogen bottle was carried out using the familiar design software “Solid works”. Figure 2 shows the nitrogen cylinder being designed for the dimensions of 230 mm outer diameter, 200 mm inner diameter, with length 800 mm, volume 100 kg/cmL. This nitrogen bottle is utilized for the simulation of the hydraulic circuit in the die casting with separate intensifier.

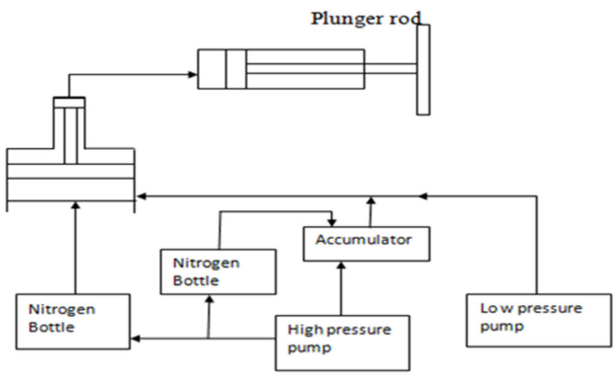

Fig. 1. Modified Circuit Diagram-Addition of N.B.

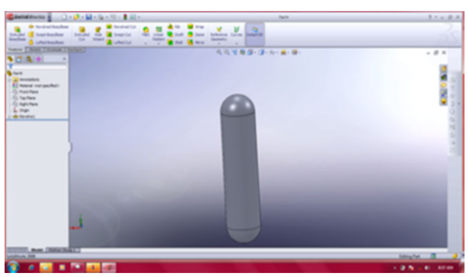

Fig. 2. Design-Nitrogen Bottle.

Figures 3(a) and 3(b) represent the graphs indicating the efficiency without and with addition of nitrogen bottle. The graphs represent five different pressures, i.e., accumulator pressure, pump pressure, nitrogen bottle pressure, intensifier pressure and actuator pressure in various colors like blue, green, red, white, and pink respectively. The pump pressure shall be same in all the three phases. It is clear from both the figures that there is a definite increase in the accumulator pressure with the addition of a nitrogen bottle in the circuit. It can also be noted from these figures that the nitrogen bottle pressure used for first phase is facilitated by first nitrogen bottle, and the second phase pressure is facilitated by second nitrogen bottle.

Earlier single nitrogen bottle supplied pressure for both the phase indicated as step graph in Fig. 3(a). Pressure lasting has been improved by 0.25 seconds after the addition of extra nitrogen bottle in case of intensifier pressure. The actuator pressure which is based mainly on the final phase of the system also gets boosted up with the addition of extra nitrogen bottle.

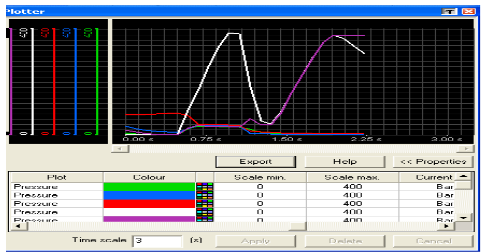

Fig. 3(a). System without the Addition of N.B.

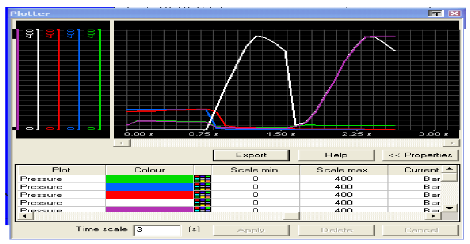

Fig. 3(b). System with the Addition of N.B.

When the accumulator was connected to the system without the nitrogen bottle the pressure to the system was only line flow which had an area pressure of 100 kg/cm^2. With the addition of extra nitrogen Bottle in the circuit the pressure got boosted to 109.110 kg/cm^2, i.e., efficiency improves from 88% to 92%. Table 3 shows the rejection level for a period of 3 months after the addition of a nitrogen bottle. It is observed that the rejection level reduces in the range of 7 to 9% on an average.

3.3. Design modification of the intensifier output passage

Figure 4(a) shows the hydraulic circuit with the intensifier output passage diameter of 16 mm. This intensifier output pressure is designed using the software “Solid Works” with an even cross section of 16 mm throughout its span of 105 mm as shown in Fig. 4(b). Figure 5(a) shows the pressure graph of 16 mm diameter output passage. It is clear that the time component achieved with this dimension for pressure boost up is 1 sec which is an indirect measure of velocity and results in efficiency of 92%. The main drawback of this design was that the metal gets partly solidified while travelling to the die itself. This led to the formation of blow holes in the output component.

Table 3. Production and Rejection after 1st Implementation.

	Constraints				1st Month				2nd Month				3rd Month			
Sl.no	Item name	End product	Alloy Grade	Weight/ piece (gms)	Production Quantity (nos)	Good Casting (nos)	Rejection Casting (nos)	Rejection %	Production Quantity (nos)	Good Casting(nos)	Rejection Casting (nos)	Rejection %	Production Quantity (nos)	Good Casting (nos)	Rejection Casting (nos)	Rejection %
1	Main body	Air Horn	LM-24	100	274	242	32	11.67	274	242	32	11.67	274	242	32	11.67
2	Ring Holder (Dia 40)	Textile Thread Extracting Machine	LM-24	28	753	680	73	9.69	753	680	73	9.69	753	680	73	9.69
3	Ring Holder (Dia 42)	Textile Thread Extracting Machine	LM-24	32	1393	1250	143	10.26	1393	1250	143	10.26	1393	1250	143	10.26
4	Bearing Saddle	Textile Thread Extracting Machine	AD C 12	25	930	817	113	12.15	930	817	113	12.15	930	817	113	12.15
5	Tension Roller	Textile Thread Extracting Machine	LM-24	22	5865	5089	776	13.23	5865	5089	776	13.23	5865	5089	776	13.23

This has been overcome by the making a design modification by varying the cross sectional area to 30 mm for about a span of 35 mm as shown in Figs. 6(a) and 6(b).

Figure 5(b) shows the pressure build up output of 30 mm passage diameter. It is clear that the time component achieved with this dimension for the pressure build up is 0.6 s, which shows that there is a remarkable increase in velocity. It is also clear that there is an increase in the discharge by 28% in the first half of the intensifier output passage (16-30 mm) and vice versa in the second half of the intensifier output passage (30-16 mm). This has led to an improvement in efficiency, i.e., from 92 to 94%.

Table 4 shows the rejection level for a period of three months after the implementation of modified output passage diameter. It is observed that the rejection level reduces in the range of 5 to 7% on an average. Therefore it is prudent that the modified design facilitates an increase in velocity there by the entire metal solidifies only after reaching the die cavity.

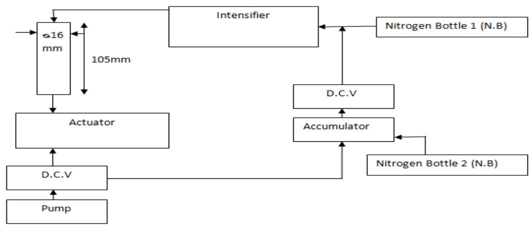

Fig. 4(a). Model with Same Passage Diameter.

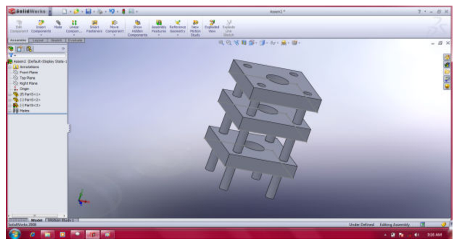

Fig. 4(b). 16-16-16 mm Intensifier Design.

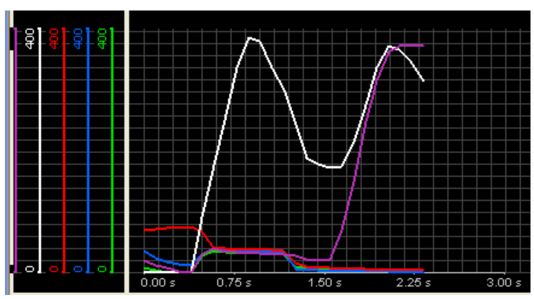

Fig. 5(a). 16-16-16 mm- Pressure Graphs.

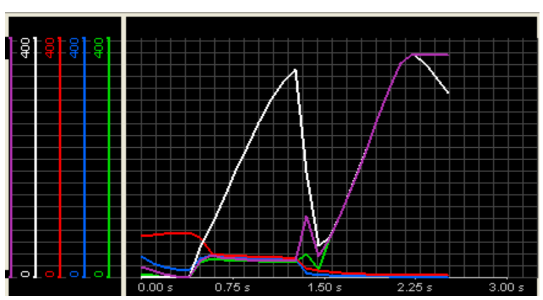

Fig. 5(b). 16-30-16 mm Pressure Graphs.

Table 4. Production and Rejection after 2nd Implementation.

Constraints					1st Month				2nd Month				3rd Month			
Sl.no	Item name	End product	Alloy Grade	Weight/ piece (gms)	Production Quantity (nos)	Good Casting (nos)	Rejection Casting (nos)	Rejection %	Production Quantity (nos)	Good Casting(nos)	Rejection Casting (nos)	Rejection %	Production Quantity (nos)	Good Casting (nos)	Rejection Casting (nos)	Rejection %
1	Main body	Air Horn	LM-24	100	274	242	32	11.67	673	633	40	5.94	673	633	40	5.94
2	Ring Holder (Dia 40)	Textile Thread Extracting Machine	LM-24	28	753	680	73	9.69	1992	1835	157	7.88	1992	1835	157	7.88
3	Ring Holder (Dia 42)	Textile Thread Extracting Machine	LM-24	32	1393	1250	143	10.26	959	900	59	6.15	959	900	59	6.15
4	Bearing Saddle	Textile Thread Extracting Machine	AD C 12	25	930	817	113	12.15	4500	4232	268	5.95	4500	4232	268	5.95
5	Tension Roller	Textile Thread Extracting Machine	LM-24	22	5865	5089	776	13.23	4346	4055	291	6.69	4346	4055	291	6.69

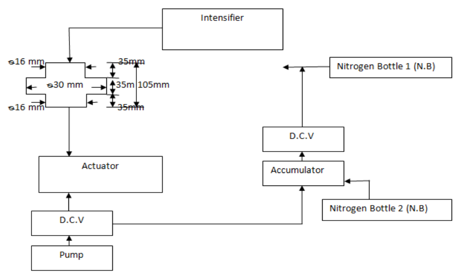

Fig. 6(a). 16-30-16 mm Intensifier Design.

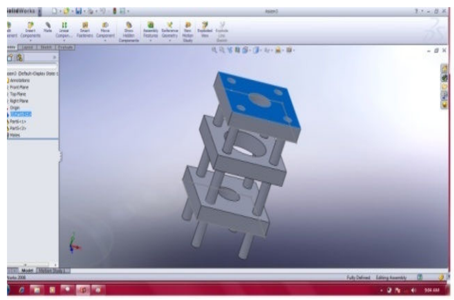

Fig. 6(b). Model with Increased Passage Diameter.

3.4. Regenerative intensifier design

The hydraulic circuit employed in the high pressure die casting machine is shown in Fig. 7. This circuit is designed in such a way that the entire operation of the machine takes place in three phases. The first phase is subdivided into 2 stages, i.e., before actuation of solenoid 1 and after the actuation of solenoid 1. Before solenoid 1 is activated the hydraulic fluid is pumped from the reservoir by the low pressure pump of capacity 35 bars and 40 LPM to the plunger directly, which assists in the movement of plunger to about 100 mm distance. After solenoid 1 is activated, the movement of the plunger stops and hence the flow is redirected to the accumulator via the shot valve 1.

In the second stage, oil is pumped from the reservoir by the high pressure pump of capacity 100 bars and 112 LPM to the plunger. The oil stored in the accumulator during the first phase partly gets added to the flow to the plunger and remaining oil gets added to the intensifier input, thereby the discharge of oil increases. In the existing system nitrogen bottle was shared between both accumulator and intensifier. After carrying out the modification, i.e., accumulator is attached to a separate nitrogen bottle (N.B 1) which mainly helps to build up the pressure further more. Due to this the plunger movement is rapid. The second phase ends up with the plunger reaching the position of Limit switch 2.

In phase 3, the fluid from the reservoir travels to the plunger. The fluid coming out of the intensifier also gets added in the flow line to the plunger which led to the pressurized fluid injection. Figure 8(a) shows the pressure graphs of the Intensification unit without regenerative circuit.

The pressure built up here sustained only for 0.6-0.8 s which was noted to be a little short. Under these conditions of pressure, the formations of the casting were not sound, marking rejection percentage as 6 and efficiency as 94%. Therefore it was decided to increase the working pressures by the addition of a regenerative circuit in the existing setup as shown in the encircled area of Fig. 7 so as to achieve sound castings.

In the modified circuit, solenoid 6 gets activated in the first phase in order to release the nitrogen bottle pressure to the Intensifier unit. Solenoid 5 which is actuated during the second phase of operation initiates the regeneration of fluid that is present in the intensifier unit, there by building up the pressure. Even though the regeneration has started earlier, it enters the third phase, and in turn to the plunger only on actuation of solenoid 3 and 4.

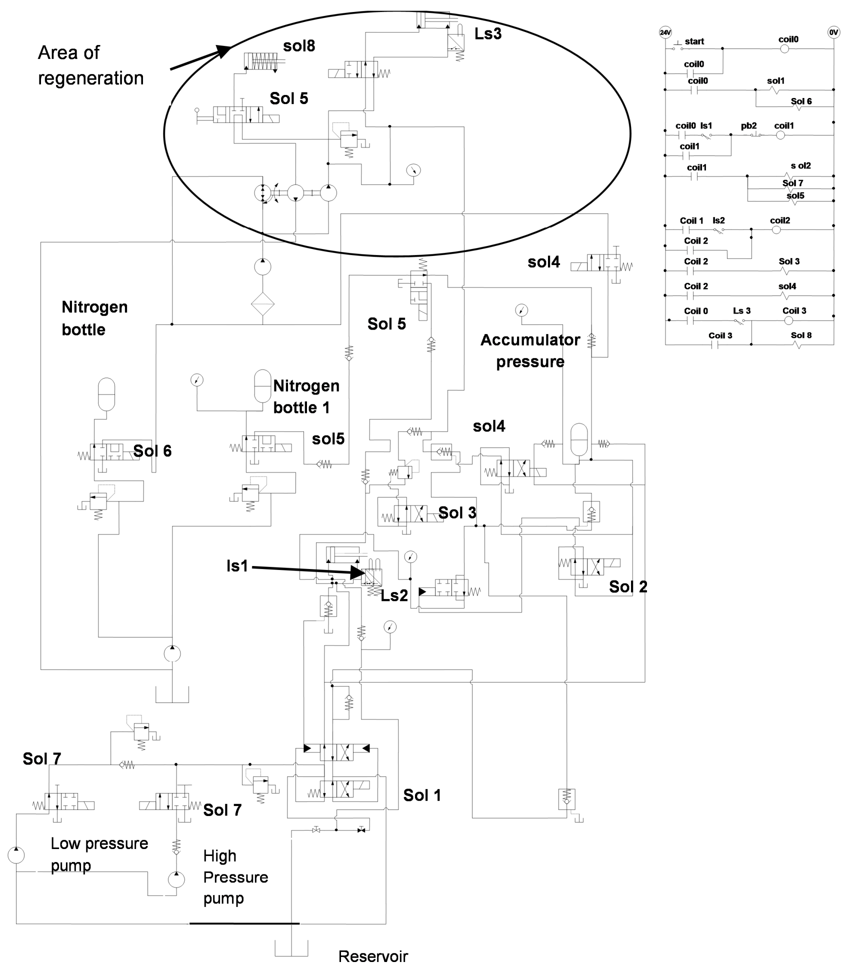

Fig. 7. Hydraulic Circuit of High Pressure Aluminum Pressure Die Casting Machine.

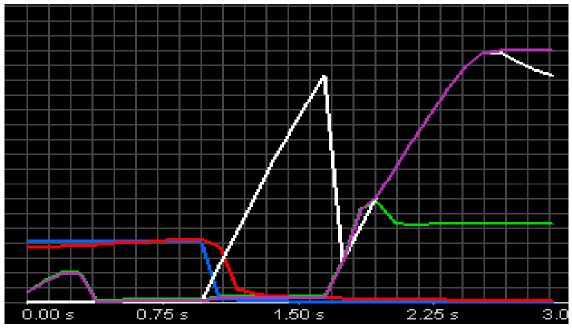

Fig. 8(a). Intensification Unit without Regenerative Circuit.

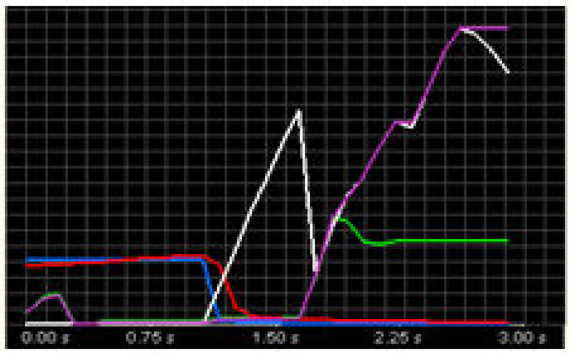

Fig. 8(b). Intensification Unit with Regenerative Circuit.

The basic intensification ratio is given as Eq. (1) [1]

$$\frac{D_1}{D_2} = \frac{P_2}{P_1} = \frac{Q_1}{Q_2} \tag{1}$$

$$\frac{(Q_1 + x)}{(Q_2 - x)} = \frac{(P_2 + Y)}{P_1} \tag{2}$$

After the addition of regenerative circuit the output of the intensifier is parted in the ratio of 3:1. Three parts are sent to the output and one is directed back to the feedback input. Equation (2) was developed by incorporating the intensifier design changes.

Finally solenoid 8 gets initiated when Limit Switch 3 is reached, which is the end of the cycle, thereby regeneration is terminated marking the end of the third phase.

Figure 8(b) shows the pressure graphs of Intensification unit with regenerative circuit. It is clear that the pressure built up sustains for nearly 1.2 to 1.6 s. This regeneration of fluid has created an increase in intensifier pressure to about 320 bars and that of actuation pressure to 360-370 bars. This has shown an increase in efficiency, i.e., from 94 to 98%. Table 5 shows the rejection level after the addition of a regenerative circuit for a three month period. It is observed that the rejection level got reduced in the range of 0 to 3% on an average.

Table 5. Production and Rejection after 3rd Implementation.

Constraints					1st Month				2nd Month				3rd Month			
Sl.no	Item name	End product	Alloy Grade	Weight/ piece (gms)	Production Quantity (nos)	Good Casting (nos)	Rejection Casting (nos)	Rejection %	Production Quantity (nos)	Good Casting(nos)	Rejection Casting (nos)	Rejection %	Production Quantity (nos)	Good Casting (nos)	Rejection Casting (nos)	Rejection %
1	Main body	Air Horn	LM-24	100	5420	5307	113	2.08	5420	5307	113	2.08	33280	32716	564	1.69
2	Ring Holder (Dia 40)	Textile Thread Extracting Machine	LM-24	28	19000	18401	599	3.15	19000	18401	599	3.15	56940	56475	465	0.82
3	Ring Holder (Dia 42)	Textile Thread Extracting Machine	LM-24	32	6740	6717	23	0.34	6740	6717	23	0.34	220	220	0	0
4	Bearing Saddle	Textile Thread Extracting Machine	AD C 12	25	1367	1324	43	3.14	1367	1324	43	3.14	4840	4840	0	0
5	Tension Roller	Textile Thread Extracting Machine	LM-24	22	49952	49413	539	1.08	49952	49413	539	1.08	5835	5809	26	0.45

4. Conclusions

The initial efficiency of the machine was 88 % that led to the rejection rate of 11-13%. 3 design modifications were carried out in order to improve the system efficiency thereby reducing the rejection rate of the component. The first design modification, i.e., addition of nitrogen bottle led to the improvement in system efficiency of 92% which resulted in drop in rejection rate of 7-9%. Second modification, i.e., intensifier output passage diameter led to the improvement in the system efficiency of 94% which resulted in drop in rejection rate of 5-7 %. Third modification, i.e., addition of regenerative circuit led to the improvement in the system efficiency of 98% which resulted in drop in rejection rate of 0-3 %. All together the design modification carried out was successful in achieving the quality components in Aluminum high pressure die casting machine.

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