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PRODUCTIVITY IMPROVEMENT IN A PLASTIC INJECTION MOULDING COMPANY THROUGH CYCLE TIME REDUCTION AND BY PRACTICING KAIZENS

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Abstract

The present work was carried out in a company manufacturing Plastic Injection Moulding Components for Textile Industries in India. The objective of the present work is to improve plant efficiency to get maximum profit. Plant efficiency can be improved by improving the following parameters from the present level: (1) Increasing machine capacity (2) Reducing down time of machines (3) Reducing rejection of products and (4) Energy conservation. After implementation of suggestions in the company, overall profit went up by Rs.48,976 /- per month.

1. Introduction

The present work was carried out in a company manufacturing Plastic Injection Moulding Components like Perforated Cone, Plane Cone, OE Cheese Tube and Ring Tube for Textile Industries in India. These components are mainly used for Textile Industry to wind up the fabric. This factory has four injection moulding machines. KAIZEN means continuing improvement involving everyone- managers and workers alike and in the present work, many KAIZENs have been recommended and implemented.

2. Objectives

The aim of the present work is to improve plant efficiency to get maximum profit. Plant efficiency can be improved by improving following parameters from the present level:

1. Increasing machine capacity.
2. Reducing down time of machines.
3. Reducing rejection of products and
4. Energy conservation.

Overall productivity has to be improved by introducing process modifications and other changes.

3. Limitations of study

Plastic Injection Moulding companies are producing many components for industrial purpose. They are producing components with many colours as per customer requirements. Mould changes and colour changes will affect the machine efficiency. Hence machine efficiency may vary based on the number of mould changes and colour change being carried out per month.

4. Plant efficiency improvement

4.1 Improving capacity of the machine

Machine capacity can be improved by reducing cycle time . Cycle time or through put time means time taken for producing one component. In this factory, throughput time to produce a component mainly depends upon the following factors: (1) Component weight, (2) Component design, (3) Material, (4) Cooling system and (5) Parameter setting

Throughput time can be improved by fine-tuning the process and methods.

4.1.1 Injection moulding process

The process involves the injection under pressure of a predetermined quantity of heated and plasticized material into a relatively cold mould. Once the material solidifies and cools in the mould because of the provision of water cooling, the mould is opened and the product is ejected. In injection moulding process, cycle time will be calculated by using the following formula:

Cycle time = Filling time + Holding time + Cooling time + Mould closing/opening/ejection time.

Filling time corresponds to the injection under pressure of a predetermined quantity of heated and plasticized material into a relatively cold mould. After filling, pressure will be maintained inside the mould for few seconds to form the required profile completely. Time taken for this forming is called holding time. Time taken to cool the moulded material in the cold mould is called cooling time. Cooling water temperature and quantity of water circulated are the major factors for fixing cooling time. Normally moulds have two halves. One is fixed half and another one is moving half. Moving half moves towards the fixed half and closes the mould. Time taken to close the mould is called mould closing time. Moving half will move back to predetermined distance from the fixed position. Time taken to open the mould is called mould opening time. After opening the mould, ejecting unit moving from fixed half ejects the component outside the mould. Time taken for ejecting the component is called ejection time. The company is producing many components for textile industries. In this study, 10 important sizes are considered. They are shown in **Table- 1.**

4.1.2 Cycle time reduction

Cycle time means time taken to produce one component. Machine capacity can be increased by reducing cycle time. Present cycle time for each component along with weight and raw material are given in **Table 1.**

4.1.2.1 Experimentation

A trial was conducted in machine A to improve productivity by reducing cycle time. A selected size along with cycle time and raw material are given below:

Size –4^{0}20" Perforated Cone

1. Raw material - Poly Propylene
2. Present cycle time - 24 seconds
3. Component Weight - 49 gms.

The cycle time of 24 seconds are divided into 4 parts.

1. Filling time - 3.5 seconds
2. Holding time - 1.5 seconds
3. Cooling time - 11 seconds
4. Mould Closing/Opening/Ejection - 8.0 seconds

Total - 24 seconds

Our trials mainly concentrated on the reduction of filling time, cooling time and mould closing/opening/ejection time to reduce cycle time.

4.1.2.1.1 Filling time reduction

Filling phase will start after clamping the mould. Injection speed and pressure will change the filling time. Injection speed increased from 45% to 50% and injection pressure increased from 56 bar to 63 bar. After this change, filling time was reduced from 3.5 seconds to 3 seconds. Likewise filling time in all sizes has been reduced by 0.5 second. The existing setting was followed for holding. After reducing injection time, no new defects in components were found. Components' weights were measured and 100 readings were recorded continuously. All the values were found within 3% tolerance only. Injection speed and pressure were increased further by 5%. Flash was noticed at many places. Hence Injection speed and pressure were reverted to 50% and 63 bar respectively.

4.1.2.1.2 Mould closing, opening and ejection time reduction

Mould opening, mould ejection and mould closing sequences in injection moulding process were also subjected to experimentation.

Mould closing, opening and ejection time is 8 seconds for the trial size perforated cone. Details are given below:

Mould closing time	-	3 seconds
Mould opening time	-	2 Seconds
Ejection time	-	3 Seconds

Ejection speed was like earlier setting of 3 seconds because component should be ejected smoothly. Otherwise component may be damaged. Mould opening/closing time (without ejection time) is seconds. Mould closing and opening speed was increased from 65% to 68% and pressure was increased from 70 bar to 74 bar. After increasing mould opening and closing speed components produced were found without any new defects. Mould opening and closing time got reduced from 5 seconds to 4.5 Seconds.

4.1.2.1.3 Cooling time reduction

After injection phase, cooling sequence will start. At the same time, material plasticization also will start for next cycle. Plasticization time should always be completed before mould opening. Hence plasticization time should be less than the cooling time. Before reducing cooling time one should consider the plasticization time because material will leak from the nozzle during mould opening. This is the condition for setting cooling time.

Presently, cooling time is 11 seconds for 4º20” perforated cone. Plasticization time is 3 seconds only because the component weight is only 49 gms. Hence plasticization time is very less when compared to the cooling time. Cooling tower pressure is very high. Consumption of cooling water is very less. Due to the high pressure, severe water leakage was noticed from the water hose. Hence operators did not open the cooling tower valve fully. Operators opened the valve only 50% to avoid leakage. If operators are able to arrest water leakage, one can utilize the full capacity of the cooling tower which will lead to more effective cooling.

Hence the company used quick release coupler at both edges of the water hose. One edge of the quick release coupler with water line and another edge with mould nipple. Operator can fix the quick release coupler with hose very firmly. After fixing the quick release coupler, no water leakage was noticed from water hose. Now the operator can open the cooling tower valve fully. The quantity of water circulation is increased. Thus, the effect of cooling also increased. Cooling was taking place with lesser time. Hence cooling time was reduced from 11 seconds to 10 seconds for this size. The components received enough cooling within 10 seconds. Components were also found free from any new defects. The cost of the quick release coupler is nominal. As per the study, if the previous cooling time = 15 seconds, one can reduce the cooling time by 1 second and if the previous cooling time > 15 seconds, one can reduce the cooling time by 2 seconds. After implementing these three trials, there was a saving of 2 Seconds per cycle for 4º20” perforated cone size.

4.1.2.2 Results

From the analysis, productivity of the 4^{0}20” perforated cone increased by 8.3% and cycle time was reduced from 24 seconds to 22 seconds for the said size. The revised cycle time details are given below:

1. Filling time was reduced from 3.5 seconds to 3 seconds.
2. Mould closing and opening time was reduced from 5 Seconds to 4.5 Seconds
3. Cooling time was reduced from 11 Seconds to 10 Seconds.

Finally, there was a 2 seconds savings in total cycle time.

Earlier cycle time	=	24 Seconds
Present cycle time	=	22 Seconds
Earlier Production	=	150 pieces per hour
Present Production	=	163 pieces per hour

Hence the productivity of the $4^0$20" perforated cone is increased by 8.3%. Similarly the cycle time for all the sizes were changed and the details are given in Table 2. After implementing the above modification, machine capacity increased by 8.7%. Revised cycle time and production details are shown in Table 2.

4.2 Reduction of rejections

Rejections are products, parts and materials which cannot be used because they did not meet the quality requirements. Rejections are mainly due to variations in manufacturing process, raw material and environment conditions.

4.2.1 Variation in manufacturing process

Variations occur in every manufacturing process. The diameter of a shaft will vary from item to item. The number of defects produced on assembly line will vary from day to day. These variations are caused by other variations such as those in material, equipment, environment and the operator's physical and mental state.

The result of manufacturing operation, for example, a certain dimension or certain chemical property, can vary in a completely random way. Random variations (chromic variation) are the result of many random causes, each cause having a small effect. It is often not possible to reduce random variations from a process. They must be accepted.

If the result of a manufacturing process does not vary randomly, there are also assignable causes of variation (sporadic variation). Assignable causes of variation can show themselves as a trend. The result changes continuously, either upwards or downwards. Usually there is one cause behind assignable variations. This one cause however may result in a large amount of variations. It is therefore important to check such variations quickly and to take measures to eliminate the cause. Such measures are often economically justified.

Revised cycle time and production details for various components are given in **Table-2**. One should concentrate on the assignable variation and the problem is to be solved permanently. The following are the major defects in plastic components which are used in textile Industries: (1) Shade Variation, (2) Silver Streaks, (3) Flow Cracks, (4) Sink Marks, (5) Weld Marks, (6)Warpage, (8) Flash, (9) Surface Waviness, (10) Burn Marks and (11) Bubbles.

4.2.2 Defects analysis using Pareto Analysis Method

All the defects are analyzed using Pareto analysis method. In Pareto analysis method, all the defects are arranged in a descending order. Major defects, which would be causing upto 80% of the total defects, will be taken for study. In the present work, out of 10 defects, 5 defects contribute to 82% of the total defects. Hence one has to concentrate on the first five defects. The defects details for the month of November 2004 are given in **Table -3.**

4.2.3 Experimentation

Five major defects are contributing to 82% of the total defects that occurred during November 2004. The root causes of the defects are studied and corrective actions taken. Defects are mainly due to process setting, mould and material. Major defects and corrective actions are listed below:

4.2.3.1 Shade variation problem

Shade variation is a common problem in all sizes. It is a processing problem. Shade variation problem was found high during the change of dark color to light color. In such situations, the operator should change the nozzle after producing 20 rejected components in order to prevent nozzles from getting contaminated. The following color changes are recommended for nozzle change: (1) Red to white, (2) Green to white, (3) Blue to white, (4) Black to white and (5) Orange to white. After introducing the nozzle change method, shade variation problem was reduced from 0.7 to 0.34%..

4.2.3.2 Silver streaks

A long thin mark or line that is silver in color found on the surface is called silver streaks. It is mainly due to moisture and volatile matter included in material. Silver streaks problem is noticed in Acrylo nitric – Butadiene styrene and Poly carbonate materials only.The following components cause silver streaks problems.

1. OE cheese tube (50 x 56 x 170)
   - Acrylo nitric - Butadiene styrene
2. OE cheese tube (64 x 70 x 170)
   - Acrylo nitric - Butadiene styrene
3. Ring tube (18 x 22 x 200)
   - Poly carbonate
4. Ring tube (20 x 26 x 210)
   - Acrylo nitric - Butadieme

Preheating the raw material is the easiest way to remove the moisture from material. One oven was arranged for preheating purpose. Preheating temperature and preheating duration is the critical parameter in preheating operation. After implementing preheating operation, silver streaks problem was reduced from 0.46% to 0.14%. The optimum setting for preheating operation is given in **Table- 4.**

4.2.3.3 Flow marks

Flow mark means some line like marking was noticed on the surface of the components. The line like marking noticed is due to improper material flow. Flow mark defects was found high in 4º 20” plane cone size and 5º 57” plane cone size. Injection pressure was increased from 56 bar to 63 bar and injection speed from 45% to 50% to reduce filling time in cycle time. After increasing the injection pressure and injection speed, flow mark problem was reduced from 0.25 % to 0.13 % .

4.2.3.4 Sink mark

Depression like appearance noticed on the surface of the component is called sink marks. Sink mark defect was found high in OE cheese tube (50 x 56 x 98) size and OE cheese tube (43 x 48 x 170) size. Resin temperature was reduced by 5º C. After reducing the resin temperature, sink mark defect was reduced from 0.23% to 0.10% . The revised temperature settings are given in **Table -5**.

4.2.3.5 Weld marks

A crack like appearance is noticed at material flow joining places. Normally melted materials are flowing in all directions and it will join at one or two places. Poor material flow will lead to weld marks problems. Weld marks defect was found high in 4º 20" Perforated cone size and 5º 57" Perforated cone size.Weld marks defects are mainly due to improper material flowing only. Hold on pressure is increased from 55 bar to 60 bar for the both the sizes. After increasing the hold on pressure setting weld marks problems were reduced from 0.19% to 0.11% .

4.2.4 Results

The company has taken corrective action against the five major defects. Over all defect percentage was reduced from 2.3% to 1.2%. Defect details for the month of November 2004 and December 2004 are given in **Table- 6.**

4.3 Down time reduction

Down time reduction is also one of the major criteria for productivity improvement. The current machine utilization is only 80%. Down time can be classified into two parts:

1. Planned down time
2. Unplanned down time.

Size change and colour changing delay time are treated as planned down time. Unexpected breakdown is treated as unplanned down time. Machine utilization varies from 80% to 85% according to size change. Down time details for the month of November 2003 are given below.

Total Down time	-	20%
Planned down time (Mould change)	-	10%
Unplanned down time (Mechanical/Electrical and other delays)	-	10%

4.3.1 Planned down time

Machine stopped for some special purpose is called planned down time. It is a pre determined operation. For example, mould change and colour change will come under planned down time. Planned down time details are given below.

1. Mould change	-	8%
2. Colour change	-	2%

4.3.1.1 Mould change time reduction

Mould change time is the time in-between completing last piece of the old size and producing first piece of new size . Average mould change time is 3 hours and 50 minutes. Details are given below:

Down time for mould change (8%)
- 3450 minutes

Number of mould changes
- 15 times.

Time taken for each mould change
- 230 minutes
(3 hours and 50 minutes)

4.3.1.1.1 Mould changing Procedure

Mould changing activity and color changing activity procedure are given below.

4.3.1.1.1.1 Man power allocation for mould change

A team of four workmen were allotted for mould changing work.

4.3.1.1.1.2 Tools arrangement

The workmen have to arrange all the tools for mould unloading and new mould loading. A checklist is needed for mould unloading and mould loading work.

4.3.1.1.1.3 Proper identification

Limit switch wire connection, mechanical bolt, nut, water, clamp and oil line should be identified properly for mould changing.

4.3.1.1.1.4 Training to all concerned

Workmen and supervisors should be trained properly for every work. Better training will lead to good performance. As a result of system modification and good training, mould changing time was reduced from 8% (4hours) to 4% (2 hours).

4.3.1.2 Colour change time reduction

The following tips will help to colour change and rejection without much loss of time.

1. Workmen should change the colour from light shade to dark shade. For example, white color to be changed to red color.
2. Workmen should change from one colour to another related colour only. For example, pale yellow to orange or light green to dark green.
3. Process settings for each color should be specified because process settings vary from colour to colour to avoid defects like flow mark and weld line.

As a result of modified colour changing method, colour changing down time was reduced from 2% to 1%. Planned down time was reduced from 10% to 5%.

4.3.2 Unplanned down time

Unexpected major and minor break down are called unplanned down time. Mechanical and electrical problem will come under unplanned down time.

4.3.2.1 Reduction of unplanned down time

Unplanned down time can be reduced by preventive maintenance method. Hydraulic oil should be maintained in good condition. The company is using microprocessor control based injection moulding machine. Electronic cards are being used in microprocessor system. The quality of these cards should be good.

Barrel heater problem is one of the repeated problems on the electrical side. Before starting, an operator has to ensure that there is no blockage of mould path. Operators are instructed to check the mould path, if machine stopped for more than 10 minutes.

Water leakage problem and mould related problems are treated as other delays. Water leakage should be stopped as much as possible.

Some of the mould related problems are listed below:

1. Mould damage due to wrong operation.
2. Water leakage from inside of the mould.

If water leakage was noticed from the mould, workmen have to unload the mould and leakage to be corrected. It will take around 2 hrs for correction. Water circulation is given to the mould to cool the heated articles. Hence in mould change check list, an additional instruction is introduced to check the condition of 'O' ring and replace the same if found damaged as a preventive measure. After that there is no water leakage problem noticed from the mould during running condition.

4.3.3 Overall down time Reduction

Over all down time was reduced from 20% to 11%. Down time reduction details are given in **Table -7.**

4.4 Variable Frequency Drive (VFD) for hydraulic oil pump motor

Hydraulic oil pump is used to supply hydraulic oil for the movement of mould closing, mould opening, ejection movement, clamping force and injection unit movements. To avoid unnecessary power consumption, a variable frequency drive is introduced in the pump motor supply.

4.4.1 Electricity expense reduction

After fixing variable frequency drive, electricity expenditure was reduced by 20%. Variable frequency drive is installed in all four injection-moulding machines.

5. Results

5.1 Introduction

Overall plant efficiency improved because of this corrective work. Results of the work are given below:

1. Rejection percentage reduced from 2.3 % to 1.2 %
2. Machine capacity increased by 8.7 %
3. Down time reduced from 20 % to 11 %

Overall productivity improvement
= 18..48 %

Electricity expense saving /month
= Rs.9,000/-

5.2 Profit improvement through productivity improvement

Plant productivity improved by 18.48 %. This is through productivity improvement by two ways.

1. Machine capacity increased by 8.7%
2. Down time reduced by 9%

Productivity improvement is converted into monetary value for calculating profit. Calculation details are given below:

Average component weight = 50 gms
Average cycle time = 30 Seconds
Production per hour = 120 pieces
Plant production per day = 4 machine x Production./ hour x 24
= 4 x 120 x 24
= 11,520 pieces

Plant production per month (30 days) = 3,45,600 pieces

Monthly raw material consumption
= 17,280 Kgs.

Overall productivity improvement
= 18.48%

Raw material consumption for 18.48 %
= 3193 Kgs.

Average profit in selling 1 kg of finished good
= Rs.12/-

Profit in selling 3193 kgs. of finished goods
= 3193 x 12
= Rs.38316/-

Improved profit because of productivity improvement = Rs.38316/- /-

5.3 Profit improvement through reduction in rejection.

Rejection percentage was reduced from 2.3 % to 1.2 %. Many savings by reduction in rejection details are given below:

Rejection reduced = 1.1 %
= 4147 pieces

Raw material consumption for 1.1 % of rejects
= 4147 x 50/1000
= 207.35 kgs.

Conversion cost for 1 kg of raw material to finished goods = Rs. 8/-

Conversion cost for 207.35 kgs. raw material to finished goods = 207.35 x 8
= Rs 1658.8/-

Profit improvement by reducing rejection
= Rs.1660 /- per month

5.4 Profit improvement through energy conservation

Electricity expenditure savings =
Rs.9,000/- per month

5.5 Overall profit improvement

Over all profit improvement can be calculated by adding the following items.

1. Profit improvement through productivity improvement.
2. Profit improvement through reduction in rejection.
3. Profit improvement through energy conservation

Overall profit improvement

= Rs.38316 + Rs.1600 + Rs.9000

Overall profit improvement per month

= Rs.48976 /-

6. Conclusion

The management has implemented all the recommendations of the project report. The overall profit of the company has improved by Rs. 48,976/- per month.

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Table- 1
Cycle time, weight and raw material for each component

Serial No.	Component name	Cycle time	Weight	Raw material
1	4º20" Perforated cone	24	49	Poly Propylene
2	4º57" Perforated cone	25	50	Poly Propylene
3	4^{0}20" Plane cone	24	54	Poly Propylene
4	5º57" Plane cone	40	60	Poly Propylene
5	OE Chease tube (50x56x170)	40	60	Acrylo nitric-Butadiene styrene
6	OE Chease tube (50x56x98)	40	84	Poly Propylene
7	OE Chease tube (64x56x170)	35	46	Acrylo nitric-Butadiene styrene
8	OE Chese tube (43x48x170)	35	57	Poly Propylene
9	Ring tube (18x22x200)	30	40	Poly Carbonate
10	Ring tube (20x26x210)	30	38	Acrylo nitric-Butadiene styrene

Table- 3

Defect details for the month of November 2004

Serial number	Name of the defect	Number of defects	Defects in %	Defects contribution
1.	Shade Variation	2076	32.64664	32.64664
2.	Silver Streaks	1284	20.22331	52.86995
3.	Flow cracks	692	10.88221	63.75216
4.	Sink marks	628	9.875767	73.62793
5.	Weld marks	532	8.366095	81.99402
6.	Warpage	335	5.268124	87.26215
7.	Flash	260	4.088693	91.35084
8.	Surface Waviness	211	3.318132	94.66897
9.	Burn marks	196	3.082246	97.75122
10.	Bubbles	143	2.248781	100

Table- 4

Preheating temperature along with preheating time and raw material.

Raw material	Preheating temperature	Preheating time
Acrylo nitric – Butadiene styrene	80ºC	2 hrs.
Poly carbonate	110ºC	3 hrs.

Table- 5

Revised Barrel temperature setting along with existing temperature setting

Equipment	Existing temperature setting	Revised temperature setting
Barrel – Zone I	220º C	215º C
Barrel – Zone II	220º C	215º C
Barrel – Zone III	205º C	200º C
Nozzle	190º C	185º C

Table- 6

Comparison table for rejection corresponding to each type of defect

Serial number	Defect's name	November 2004	December 2004
1	Shade Variation	2076 (0.75%)	1154 (0.34%)
2	Silver Streaks	1286 (0.46%)	476 (0.14%)
3	Flow cracks	692 (0.25%)	464 (0.13%)
4	Sink marks	628 (0.23%)	351 (0.10%)
5	Weld marks	532 (0.19%)	385 (0.11%)
6	Warpage	335 (0.12%)	347 (0.10%)
7	Flash	260 (0.09%)	304 (0.08%)
8	Surface Waviness	211 (0.07%)	240 (0.07%)
9	Burn marks	196 (0.07%)	208 (0.06%)
10	Bubbles	143 (0.05%)	155 (0.04%)
	Total	6359(2.30%)	4084(1.20%)

Table- 7

Overall down time reduction

Down time details	November 2004	December 2004
Planned down time		
Mould loading/unloading down time	8 %	4 %
Colour change down time	2 %	1 %
Planned down time	10 %	5 %
Unplanned down time		
Water leakage down time (From water lines and from mould)	2.5 %	0 %
Hydraulic related problem	3 %	1.5 %
Mould related problem (Damage & other Correction)	3.5 %	4 %
Heater problem (Electrical delay)	0.5 %	0 %
Power future and Electronic delay	0.5 %	0.5 %
Unplanned down time	10 %	6 %
Overall down time	20 %	11 %

Table- 2
Revised cycle time and production details for various components

Sl. no.	Component name	Earlier injection time in secs.	Earlier mould closing./ opening. time in secs.	Earlier cooling time in secs.	Earlier total cycle time in secs.	Revised injection time in secs.	Revised Mould closing ./opening. time in secs.	Revised cooling time in secs.	Revised total cycle time in secs.	Time saved in seconds	Productivity improvement per hour	
											Nos.	%
1.	4º 20” Perforated Cone	5	8	11	24	4.5	7.5	10	22	2	13	8.6
2.	5 º57” Perforated Cone	5	8	12	25	4.5	7.5	11	23	2	12	8.3
3.	4 º20” Plane Cone	5	10	15	30	4.5	9.5	14	28	2	8	7.1
4.	5 º57” Plane Cone	8	8	24	40	7.5	7.5	22	37	3	7	8.1
5.	OE Chease tube (50 x 56 x 170)	6	12	22	40	5.5	10.5	20	36	4	10	11.1
6.	OE Chease tube (50 x 56 x 98)	6	11	18	35	5.5	10.5	16	32	3	10	10.3
7.	OE Chease tube (64 x 70 x 170)	6	12	22	40	5.5	10.5	20	36	4	10	11.1
8.	OE Chease tube (43 x 48x 170)	5	12	18	35	4.5	10.5	16	31	4	14	13.8
9.	Ring tube (18 x 22 x 200)	4	8	18	30	4.0	8	16	28	2	8	7.1
10.	Ring tube (20 x 26 x 210)	5	10	15	30	4.5	9.5	14	28	2	8	7.1