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Design and Development of Automation System for Polyurethane Foaming Machine

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Abstract: *PU foams are extensively used in the automotive sector, mainly for car seats, headrests, (air-conditioning) filters and acoustic insulation. Depending on the application they are being used for; these foams have to comply with specific performance and emission standards for the automotive industry. The purpose of the project is to control and maintain the temperature, pressure, flow control and curing time of foaming process to maintain global performance requirements for poluurethane(PU) foams in terms of density, hardness, durability, support factor, touch etc. A manual and semi automatic system lacks in quality and also requires lot of labor and energy. This project was undertaken to implement fully automatic process for manufacturing and testing. As a part of the automation sensory feedback operations, flow control calibrations and robot was implemented, the program selection was done using the feedback from the sensors which also included RFID (Radio frequency identification) and limit switches. So as to produce global standard PU foams with minimum labor and higher production rate and lower rejections.*

Keyword: *Polyurethane, Isocynate, Polyol, Radio Frequency Identification.*

1. Introduction

Polyurethane (PU) stands for a group of products within the family of polymers or plastics. Manufacturers make polyurethane foam by reacting polyols and isocyanates, both products derived from crude oil. In the production of polyurethane foam three basic raw materials play a key role: polyol, isocyanate and water. Agents, such as catalysts and stabilizers, are used to support the chemical process.

- Polyol: Is a synonym for polyalcohol, which is obtained from propylene and/ or ethylene oxide
- Isocyanate: It is a highly reactive substance which easily binds with other substances like alcohol, determining the rigidity of the PU foam
- Water: creates reaction with isocyanate and carbon dioxide which acts as blowing agent in the production
- Catalyst: speeds up the reaction process and ensures equilibrium in the polymerization and the blowing reaction.
- Stabilizer: ensures the homogenous structure and stabilization of the cellular network in the reaction process up until the time that the foam has fully risen.

Further additives can be added to obtain specific product properties. The proportion between the speed of the foam reaction and the polymerization reaction is the most important process parameter: if the first one goes fast the foam "explodes" and hence collapses. If the second one goes too fast the foam creation will be retarded, the foam stays self contained and crimps while cooling. This is called the 'Critical curve of foaming': only a good proportion (specific to every single kind of foam) creates appropriate foam. From previous research it is understood that the tensile strength and elongation at break reduces with an increase in amount of filler in the PU matrix for all particle sizes and Morphological examination of the foam indicated that cell geometry characteristics exerts a significant influence on mechanical properties **[1].** Further various experiments were conducted for improving mechanical properties and cost effectiveness of PU foam one such attempt is chemical modification of its structure **[2]**. There are five types of foam composites produced by one-shot free rising method in a closed mould. The organic compounds whereas 96.9% in tyre are formed by aromatic oil, carbon black and rubber hydrocarbon (RHC). Besides, the results of thermal analysis indicated coir fibers and tyre particles are suitable to use as fillers for PU foams since they have high decomposition temperature **[3].** However the natural fiber-reinforced polymer composite is rapidly growing both in terms of their industrial applications and fundamental research. They are renewable, cheap, completely or partially recyclable and biodegradable **[4]**. These composites are having low density and cost as well as satisfactory mechanical properties make them an attractive due to easy availability and renewability of raw materials. Natural fibers have been proven alternative to synthetic fiber in transportation such as automobiles **[5]**.However in large productivity environments industries are preferring synthetic foaming these Foams are perceived as a "premium" foam product for mattresses toppers and pillows but at the same time, the labor and energy intensive including several production steps process requiring moulds, freezing, vulcanizing, washing to remove additives and then drying besides to be presented generally higher density and cost than PU **[6].**

2. Earlier Methods

Basic method includes individual fixed moulds, rail guides with mixing head mounted at the end of rail guide along with the pre allocated program panels which requires highly skilled workers to perform pouring operation for foaming. The production was only 10 moulds per cycle with 7 operators; in addition to this 2 operators were used for trimming and storing purposes. Wastage rates were high which resulted in higher rejection rate, Hence the mould quality was based on the skill sets of the operator and the production output per shift varied accordingly. The rejection rate was based on excess flow of foam, thus cleaning of moulds were difficult. The earlier process was dependant on quality gradient. **Figure 1** show the mould production and rejection number per shift.

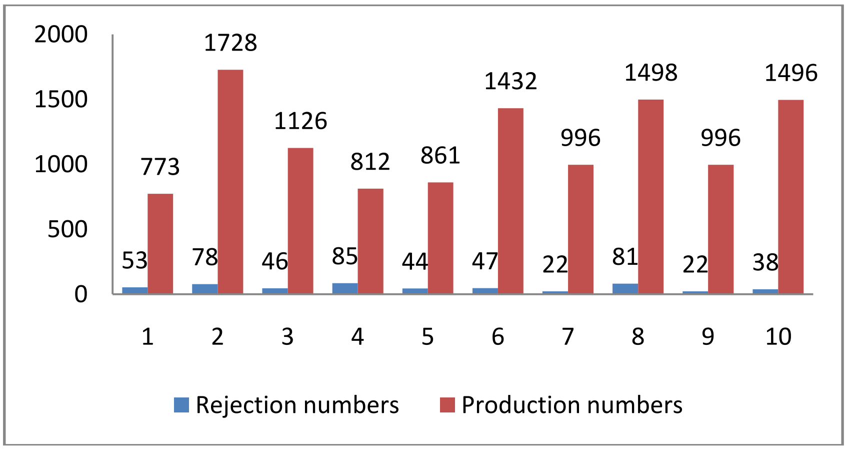


Fig1. *Production and Rejection graph*

3. Implementation

The foaming process per cycle includes calibration process in which the pressure, temperature, flow of the liquids are measured and calibrated based on the calculations using flow meter, Pressure transducers, and temperature transducers. Operators are replaced with robot which performs pouring operation based on the auto selection of programs using RFID detection to call the program and the rotary table includes fixed wheels on which the rotary table is mounted on mould station above which the moulds are placed, the opening and closing of moulds are triggered using limit switches mounted at the base of the mould station with a specific dog at each station along with the RFID tags. The locking of moulds is based on sensor output to PLC which triggers pneumatic cylinders to ensure fixture of moulds. The emulsion that is created while mixing the raw materials will be cast on a Rotary table with vertical variable boards with the moulds pre heated to 45^{o} C with the help of heater. Some seconds later a crème-like emulsion is formed, the volume expands and the foam is formed, which is then removed and the mould is sprayed with removing agent and air.

The process of PU foaming depends on:

- The chemical composition and thickness.
- Temperature
- Pressure
- Flow control
- The volume-solid matter/air ratio.
- The concentration of the mixture(isocynate and polyol)

4. Methodology of Foaming Process

The Foaming Process Includes 9 Steps;

4.1. Preparation

It is a process of preparing releasing agent, Check for the sequence of operation along with the weight of the white spirit (118-122Kgs), no odor, no spillage. Pour 7Kgs of release agent into white spirit barrel, agitate with air, fill in the pressure feed container.

4.2. Mould Preparation

It is a process of preparing the mould before stating molding process. Check for mould temperature (45-48 degrees) and surface cleanliness. Clear the vent channels by applying the releasing agent and blowing air, fix the non woven fabrics install frames and insert wires.

4.3. Chemical Pumping

It is a process of pumping the chemical into the pressure /pressurizing container. Check grade/batch number, check for the expiry date along with leakage/damage and feed pump function. Ensure no chemical in the previous barrel, open the new barrel and transfer the pump into new barrel.

4.4. Program Setting

It is a process of setting program to the logic based on the product data wiring. Check for the product data setting. Change the program number along with the injection timing, with the ISO flow rate.

4.5. Chemical Injection

In this process the mould is getting closed after pouring and kept under 3-4 bar pressure for 3 minutes. Check for the program number which includes the pouring pattern also clear the mixing head

4.6. Demoulding

Crushing is required to remove the CO_2 gas from the foam. Check for the curing time and ensure no surface defects. Demould the foam and perform crushing.

4.7. Trimming

In this process the excess flashes are removed. Check for surface defects, ensure no damage during crushing and no excess trimming and store in the curing trolley.

4.8. Hardness Checking

In this process, the part is inspected for visual defects along with hardness. Check the size, positioning and hardness specification of the indenter, along with the part number, production date and time. Allow for curing up to 1hour, load into the hardness testing machine, check for hardness, if not ok then raise Flash report. If ok then receive the value.

4.9. Post Curing and Storage

It is a process of storing the component after trimming process takes place.

5. Experimentation

The purpose of the project is to control and maintain the temperature, pressure, Flow control and curing time of the foaming process, the main challenge is to meet the required temperature for foaming, acquire specific pressure and the specific flow rate, which are accomplished using sensory network connected to plc. The experimentation process mainly includes;

5.1. Preconditions

This mainly includes monitoring of the following parameters such as ISO actual flow and polyol actual flow and ensures flow accuracy limit switch positions and alarms the precondition shown in screenshots of HMI shown in Figure 2 and 3

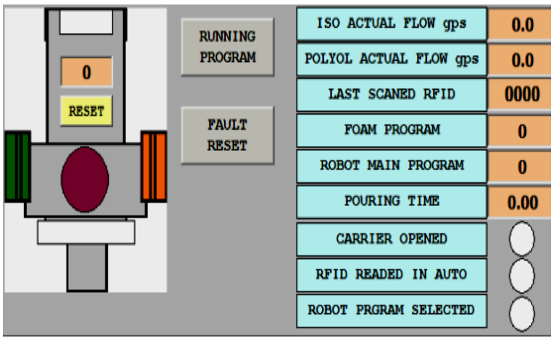


Fig2. *Initial start setup screen*

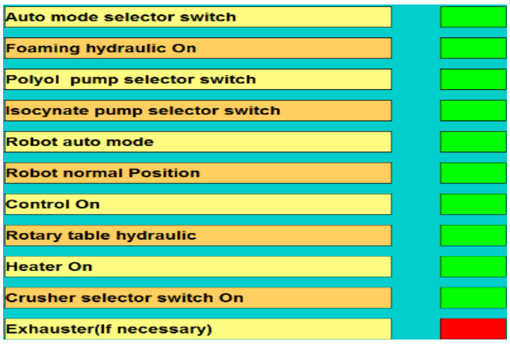


Fig3. *Initial setup*

5.2. Functions in Rotary Table

The opening and closing operation of the moulds are based on the limit switches mounted at the base of the rotary table; each mould station consists of 4 limit switches and 2 sensors dedicated to the opening and closing of the sensors. Figure 4 shows the plant setup with rotary table along with robot performing pouring. The robot program selection is based on the RFID cards attached to the table which generates a Hexadecimal code from which the program for a specific mould is selected from PLC. The rotary table consists of a Motor to drive the table wheels along with pneumatic compressor for the pneumatic cylinders which are used to perform locking operation of the moulds.

Fig4. *Setup of Rotary table with mould bases and robot*

5.3. Calibration

In this process the auto calibration includes the analog signals in terms of voltages corresponding to the suitable motor RPM, which is commissioned based on the calculations i.e., shown in the figure 5 & 6,

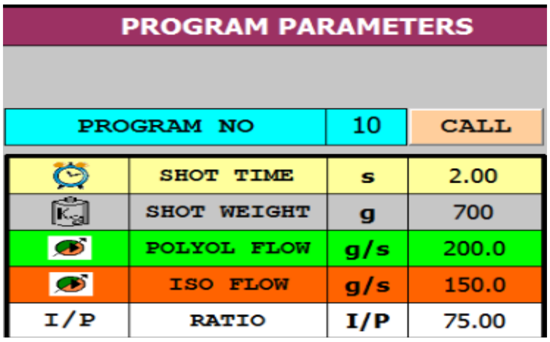


Fig5. *Program parameters*

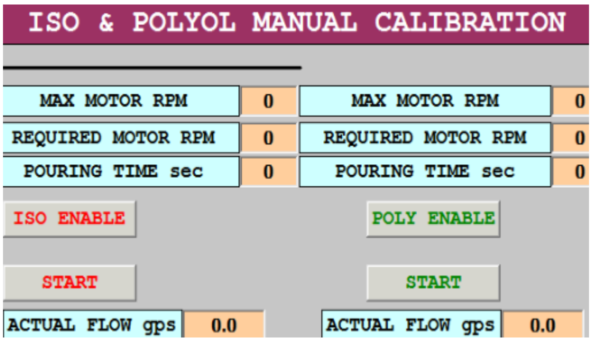


Fig6. *Isocynate & Polyol calibration*

Analog signals are categorized from 0 to 10V and the motor speed ranging from 0 to 1000RPM.

The RPM of the motor is divided by voltage for specific intervals, 1000/30=33.3 and voltage distribution= 10/30=0.33V

Hence a 0.33V increase in an analog meter will increase the RPM of the motor by 100.

Top RPM is obtained by adding 0.33, 10 times i.e., up to max of 10V.

STEPS: isocynate calibration, polyol calibration,

5.3.1. Steps

- Enter the motor RPM in table.
- Calculate the analog voltage for corresponding motor RPM.
- Enable calibration
- Start calibration
- Run the motor in entered RPM for 4 seconds each
- Update the corresponding flow of ISOCYANATE & POLYOL in PLC memory.
- Complete all the RPM.
- Stop calibration.

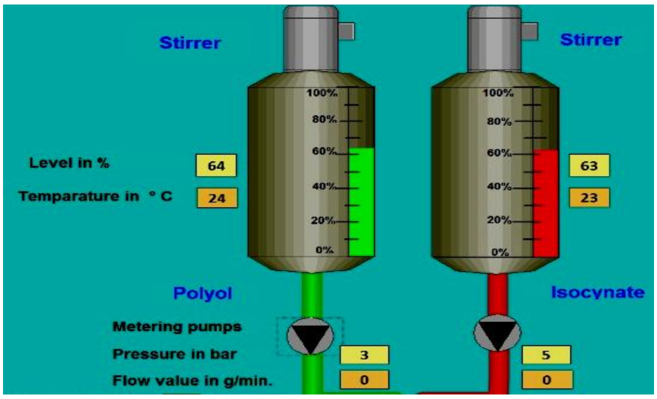


Fig7. *Flow control and temperature control screen*

5.4. Robot Program Selection

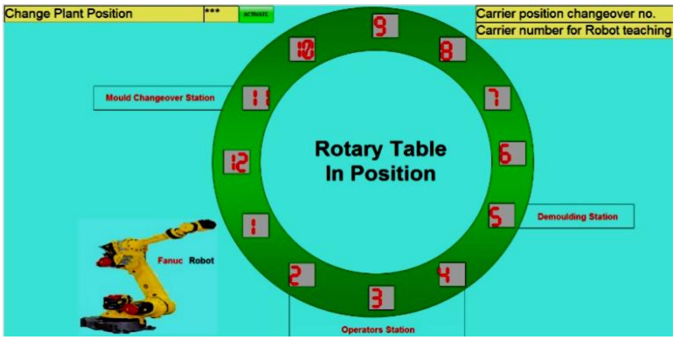


Fig8. *Robot program selection based on mould numbers*

The robot program selection is mainly based on RFID; the tags attached at the bottom of the mould are assigned to the specific programs according to their codes, that is the tags are preassigned to the PLC to perform pouring for specified moulds. Figure shows the mould numbers on which the specific program is selected.

5.4.1. Steps For Robot Program Selection

- Read RFID
- Sense the change in RFID through scanner
- Search for the carrier based on the tag value (Hex value of RFID).
- TAG value should not be 0

- If the TAG value is found in the saved carrier data
- Check for mould enable.
- Search for robot program
- Robot program call
- Start robot; calculate the motor RPM for corresponding foam parameters using calibrated values.
- Foam program selection from robot
- call the program parameters found in plc memory
- Run pre circulation using calculated values.
- Perform pouring
- Robot home position

CARRIER NO	RF ID HEX CODE	ENABLE/ DISABLE	ROBOT PRG NO
1	0000		0
2	0000		0
3	0000		0

Fig9. *Robot program selection screen*

5.5. Datalogging

Data logging is a process of collecting all the available information in the ongoing process. In this process a separate PLC is mounted and the feedback from all the sensors and PLC's are taken into new PLC. Figure 10 shows the values stored in the PLC at each cycle,which includes Robot program selection, RFID code,foam program, actual filling level, maximum refilling time, flow rate, pressure, temperatur.

Parameter foaming machine					Polyol	Iso
Pump lead time	sec	1.5	Working time edge filter polyol	Sec	30	30
High pressure tracking time	sec	5.0	Break edge filter	Sec	500	500
Low pressure tracking time	sec	2.5	Flow rate low pressure	g/min	5000	2000
Mixing head cleaning time manual	sec	9	Flow rate high pressure	g/min	10000	6000
Mixing head cleaning time auto	sec	0.5	Correction factor measuring	cm3/	1.000	1.000
watchdog hydraulic pressure rise	sec	28	Flow converter scaling factor	min	14000.0	6875.0
			Min pressure for foaming	Bar	50	25
			Max pressure cut-off	Bar	220	150
Parameter Common						
Tracking time exhauster	sec	360	Tracking time crusher	Sec		120
Conveyor motor speed max	rpm	1200	Carrier waiting time at Robot if disabled	Sec		8
Conveyor motor speed min	rpm	200	Shot Count-Mixing head		396201	Reset
Conveyor motor speed joging	rpm	250				
Auto air On time	sec	3				
Auto releasing agent On time	sec	5				

Fig10. *Stored data*

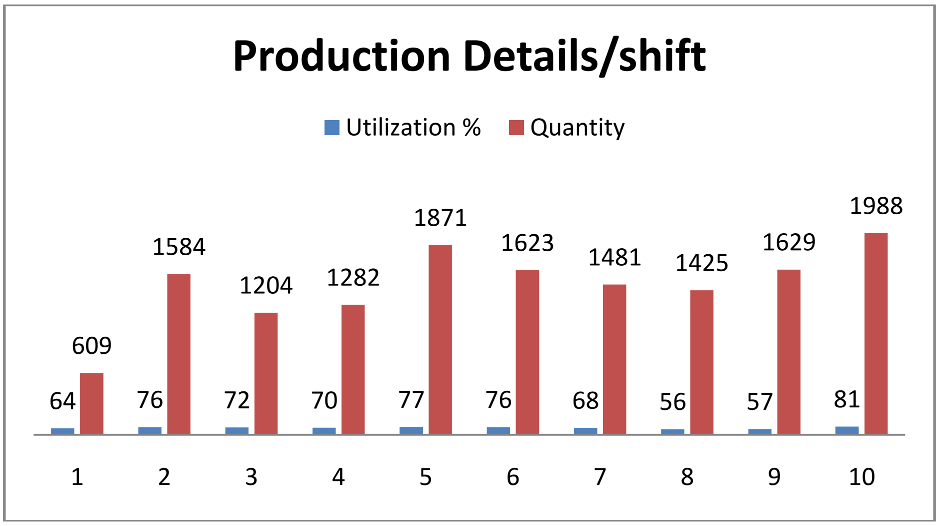
6. Results and Discussion

The project was successfully implemented with the desired outcome by maintaining the desired values and storing them as shown in below figure 11, thereby concluding with a higher quality rates, effective utilization, efficient system and increased production per shift, reduced rejection rates along with increased mould capacity.

ACTUAL MEASURED VALUES		
POLYOL TEMPERATURE	24.70	° C
ISOCYNATE TEMPERATURE	22.99	° C
POLYOL LEVEL	62.00	%
ISOCYNATE LEVEL	62.00	%
POLYOL PUMP STATUS		
ISOCYNATE PUMP STATUS		
NOMINAL FLOW OF ISOCYNATE	0	g/min
ACTUAL FLOW OF ISOCYNATE	0	g/min
NOMINAL FLOW OF POLYOL	0	g/min
ACTUAL FLOW OF POLYOL	0	g/min
MAX CUT-OFF SETPOINT ISOCYNATE PRESSURE	150	Bar
ACTUAL PRESS. OF ISOCYNATE	5.00	Bar
MAX CUT-OFF SETPOINT POLYOL PRESSURE	220	Bar
ACTUAL PRESS. OF POLYOL	3.00	Bar

Fig11. *Stored values*

The rotary table is mounted with 32 moulds and the cycle time for one complete rotation is 7 minutes, in contrast to the earlier process of 10 moulds with 7 operators with cycle time up to 10mins and high rejection rate. The graph below shows the overall equipment effectiveness and the production growth. The below graph shows the improvised production details with increased utilization and quantity,



Graph2. *Production details per shift*

7. Conclusion

The table 1 & 2 below shows the improvisation in the project outcome with contrast to the basic methods and the current project.

Before Automation;

Table1. *Foaming before Automation*

Capacity/shift	Mould production numbers/shift	Mould Rejection numbers/shift
950	773	85

After Automation;

Table2. *Improvisation after Automation*

Capacity/shift	Mould production numbers/shift	Mould Rejection numbers/shift
2810	1496	22

7.1. Overall Equipment Effectiveness (OEE)

The table below contains the OEE data of the project, in which the rejection % reduction, improvisation in the utilization of the components are shown; Table 3 & 4 shows the contrast before and after the implementation of Automation. The plant utilization depends on the production based on customer requirement.

Before Automation;

Table3. *Before Automation*

Rejection %	Plant Utilization%
6.8%	65% to 72%

After Automation

Table4. *After Automation*

Rejection %	Plant Utilization%
2.04%	97% to 100%

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