Paper ID 82

# Design and Fabrication of an Automatic Ruler Printing Machine

SS Vitharana#, WVPP Madhumali, GATD Herath, WSP Fernando and DH Marabedda

*General Sir John Kotelawala Defence University*

# vitharana1996@gmail.com

**Abstract:** Automation has been popular among most manufacturing and production systems due to improved efficiency, high production rates and low wastage. The project was focused on Designing and Fabrication of an Automated Ruler Printing Machine for stationary item manufacturing industry. The main objective of this research was to fully automate the twelve-inch ruler printing mechanism which was currently based on manual production methods. Due to the drawbacks of existing ruler printing processes of Sri Lanka, the mechanism was proposed to be automated in order to minimize consumption of human labor and time while improving safety, production hours and production rates of the manufacturing process. The research was focused on automating basic functions of ruler printing process such as loading, unloading, cleaning, printing and packing to reduce the human involvement in the process. Thus, the proposed method basically focusses on rotary indexing mechanism to synchronize all the functions of the manufacturing process to support the continuous loading and unloading of rulers. It was designed to increase the rate of production by printing four rulers at once while saving the cost of labor by reducing human involvement by automating main functions of the manufacturing process.

The research was focused on introducing online packing section and inbuilt ink drying mechanism to reduce the work in process (WIP) and lead times during production while improving accuracy and efficiency of the process by using a compact design.

**Keywords**: automated ruler printing machine, screen printing, loading, unloading

## Introduction

Most of the stationary item manufacturing companies in Sri Lanka uses manual / semi-automated methods to print rulers. Normally, semi-automated screen-printing machine which use to print twelve inch rulers require the engagement of two employees and packing process is done separately with the involvement of another employee. Due to the manual interference, some drawbacks have identified which affects the production speed, accuracy, efficiency and production time. Loading, unloading and handling of rulers consumes much time compared to printing time. Another issue related to the process is that rulers need to be kept for drying about 20 minutes which increase the manufacturing lead time of printed rulers. While these issues persists, increasing production can only be done with extra shifts, concerning the safety of the workers, this would be limited to day shifts only. To overcome the drawbacks, semi-automated screen-printing machine is to be replaced with a fully automated screen-printing machine without the interference of the human. The aim of this research is to design and implement an automated ruler printing machine for stationary item manufacturing industry to improve the current productivity and to overcome the drawbacks of the existing semi-automatic system. This proposed method spans from designing a rotary indexing-based ruler printing machines with a conveyor, fabricating and developing control system to commissioning of machine to the production line.

## Methodology

The steps of the current semi-automated mechanism of twelve-inch printing machine can be shown as in the following flow chart.

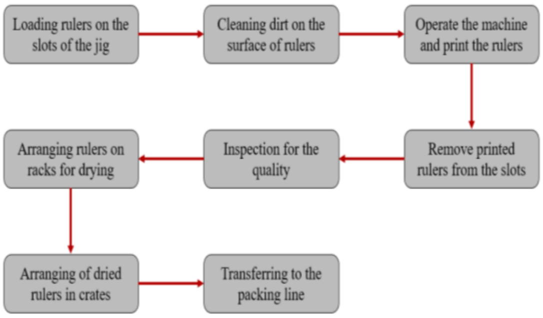


Figure 1. Flow Chart of Existing Process

The new system was proposed to overcome drawbacks of current system and main steps were identified to develop methodology associated with the proposed system.

The main focus of this research was tended towards automating loading, cleaning, printing and unloading mechanisms since those were observed as the key functions of the entire process. For this, a rotary indexing mechanism was proposed since it supports continuous feeding of rulers and unloading, compactness of the design, simplicity and cost effectiveness of the mechanism. In addition, separate automated mechanisms were proposed to be implemented for loading, cleaning, printing, unloading and conveying process.

As the first step unprinted rulers which were taken directly from the molding process are stacked on the loading unit by the machine operator. Here it was proposed to use two separate loading units to load onto two different stations of the rotary bed. Printing unit was proposed to be implemented at the third station of the rotary bed for the printing process and it was identified as the bottleneck of the manufacturing process. Moreover, the printing rate and other essential parameters for handling the printing will be set by using a Human Machine Interface operated by the machine operator.

At the final station, it was proposed to implement the unloading mechanism which will be introduced to the conveying process. Based on the sensor inputs from the attached sensors the respective actuators will be manipulated by the computerized control system (PLC's, microcontrollers) to release the loaded rulers, clean, print, and unload the printed rulers on to a conveyor for the drying process and then convey the rulers to the online packing section.

The machine as designed to interrupt by any safety measuring sensor signal or emergency stops that were performed by the machine operator. The whole system was proposed to be programmed using microcontrollers and the feedback alarms will be generated based on the pre-programmed working conditions and safety measures. A computerized system will be used to hold the feedback of the production data. Finally, the printed rulers will transfer through conveyor with drying units which installed on the conveyor to dry wet ink on the printed rulers and at the end they will be packed by the employees working at the online packing section.

## Design

The machine was designed to perform the task of fully automatic ruler printing mechanism. Designing was done with the SolidWorks software and major concerns of the design tends towards adjusting mechanisms and manufacturing flexibility. Manual adjustments were added during designing to overcome the practical problems arise during production and maintenance.

Another area covered in this design was manufacturability aspects. All the parts were designed to be manufactured with the aid of available technology to overcome the unnecessary machining costs and maintenance costs. Methods of maintenance and repair were considered since the machine was planned to be used for long run and to increase the productivity of the process.

The design of Automatic Ruler Printing Machine was developed by dividing into two main parts.

i. Rotary Bed
ii. Conveyor with Drying

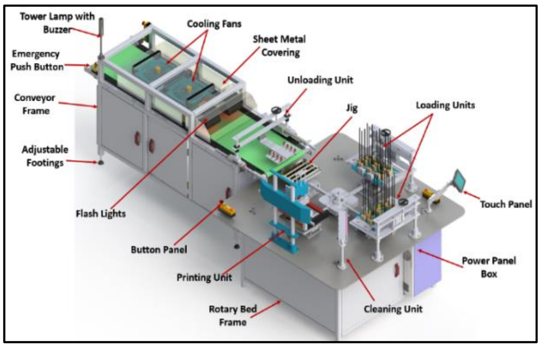


Figure 2. Complete 3D Model of the Machine

A. *Rotary Bed*

Rotary bed can be illustrated as the main functional unit of the machine and it was designed by using the Rotary Indexing Mechanism in order to link each and every step of the ruler printing process.

The unit includes a table with a rotating jig arrangement which was used to hold the unprinted rulers. As in a typical rotary indexing mechanism, stations were fixed to the table. There were four stations fixed in the machine. They are;

i. Loading Station
ii. Cleaning Station
iii. Printing Station
iii. Unloading Station

In the rotary bed, jigs were used as the working carriers and design was done to print four rulers at once. Jig comprises of square shaped slots to mount a sensor to sense the presence of the ruler before printing. The design was optimized with four key bars holding the four jigs each at a 90-degree angle. A nylon roller assembly was designed to be mounted under the key bar as a support to withstand the tension of key bar while printing. Since whole design was based on rotary indexing mechanism bearings were used for smooth and long-term functionality. Total axial load was calculeted inorder to select the appropriate bearings. Here a bearing holder was used to hold two roller bearings and one thrust bearing.

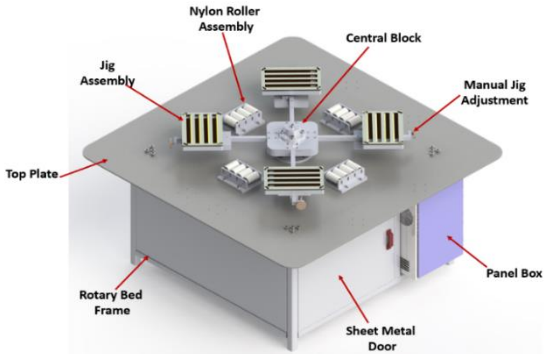


Figure 3. Rotary Bed

Manual adjustments were used where ever it necessary to overcome the practical issues. The whole rotating jig arrangement was driven by the power transferred by the main shaft. The shaft was connected to the gear box and keyway was used to couple the gearbox to the shaft. Since jigs had to be stopped at precise locations a servo motor was used and by using its feedback, jig arrangement set to rotated in 90-degree angles in predetermined intervals.

To estimate the power required for the servo motor, calculations were done to measure power required to overcome the frictional torque and power required at maximum angualr velocity.

Power required to overcome the friction between shaft and trust bearing was calculated using the equations (1) and (2),

$$M = \frac{2}{3} * \mu_k * F_{Load} * \frac{R_o^{\ 3} - R_i^{\ 3}}{R_o^{\ 2} - R_i^{\ 2}}$$

$\mu_k$=0.6 (steel) (1)

$M = 80.3Nm$
P= $\tau\omega$
P= 84W

Power required at maximum angular velocity calculated using the graph.

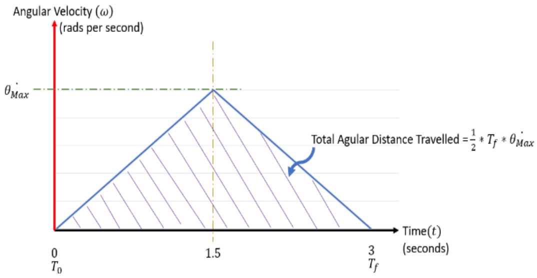

Figure 3. Graph of power required at maimum angular velocity

$$\frac{\pi}{2} = \frac{1}{2} * 3 * \dot{\theta}_{Max} \quad (2)$$

$\dot{\theta}_{Max} = \frac{\pi}{3}$ , $P = \tau_{Assembly} \times \omega$

$P = 19.5$W

Accordingly, total power required for the servo motor of the rotary bed was 103.5W.

The first and second station of the machine was designed to be used for loading of twelve-inch rulers into slots of the jig. The loading mechanism was designed to feed rulers automatically to the jig and due to the complexity of the design, unit was designed to load two rulers at first station and other two at second station. Guiding rods were placed to guide rulers smoothly on the slot of the jig and they have the ability of loading 150-160 unprinted rulers at once. Manual labor was required to refill the slots when the stack was running low and time hich takes to refill the slots was calculated the refilling frequency as 30-40 minutes. For the gripping and releasing of rulers, pneumatic cylinders were used, and a manual adjustment was used to do fine adjustments of the unit.

Third station of the rotary bed was used for printing. Printing on the rulers was the most crucial since if there any misalignment in the machine, the quality of the print will be lost. Rubber squeegee was used to uniformly distribute ink on the surface of the silk screen where blade was placed to remove excess ink on the sides of the screen. This unit was based on two axis movement principle and linear bearings with a guide rail and pneumatic cylinder was used for the horizontal motion of the printing head. For the vertical motion two compact cylinders were placed and two bearing shafts were used for smooth motion. In an occasion where one ruler is not present on the jig, the printing cannot be done as it will damage the silk screen which will result the blots in the print. This will lead to replace the silk screen which consumes more time causing production loss. Thus, the unit was designed to eliminate these cases by rotating another round to fill the missing ruler without being printed. Therefore, to stop the damages to silk screen, fiber optic sensors were used to check the availability of the rulers before arriving the printing station.

Fourth station of the machine was designed to unload the printed rulers from the jig and transfer them to conveyor for drying process. At this station unloading was performed automatically and the entire unloading unit was designed to be operated automatically with the power of pneumatics. The unloading unit can be actuated through suction-based mechanism using eight suction pads, two for each printed ruler. Suction pads were mounted on the unprinted area since unit was designed to suck the printed rulers with wet ink. Unloading unit was designed as separate unit to be mounted on the conveyor frame for easy manufacturing and maintenance activities. This has a combination of vertical and horizontal movements to achieve the function of pick and place the printed rulers and the unit was designed to match the speed of the printing.

To remove the dust particles which are stuck on the surface of the unprinted rulers during the molding process a cleaning unit was mounted in between loading and printing station. In this design a combination of wiping and air cleaning method was employed to remove the dust particles on the unprinted rulers and to ensure no dust particle retains on the surface as they reach to the silk screen of screen-printing unit. By using a compressed air flow and a piece of sponge all the dust particles will be removed from the ruler surface while the jig is rotating. This cleaning process was designed to cut down the damage, wear and the frequency of replacing the silk screen of printing unit which helps to keep the production rates constant and efficient. This design was done to achieve a profitable production rate and to improve efficiency of the process by replacing the manual dust removing method.

### B. *Conveyor*

Conveying process of this model was designed to be used as a bridge between unloading and packing mechanism of the ruler printing machine. The conveyor was designed with heat resistant belt which will support the dry the ink of printed rulers and introduce them to the online packing process. Unloading unit was attached on one side of the conveyor and at the other end packing process will be done continuously.

Conveyor was designed with a belt driven mechanism with all tension adjustment mechanisms on it. Normally conveyor was designed to be continuously at running mode which is synchronized with the speed of the printing unit. The conveyor was created as an independent unit which was attached to the ruler printing machine for easy layout changing and moving and all the parts are designed for easy maintenance and replacements.

The new model was equiped with an inbuilt drying unit which mounted on the conveyor which will directly lead to online packing mechanism. In this design, a pair of Flood Lights and a pair of Industrial Cooling Fans were used separately, and they were mounted on the top of the conveyor by using a profile bar frame. The flood lights with a power of 500W were covered with a sheet metal shield to improve safety and to minimize the power loss of the unit. A sheet metal covering was used to cover Cooling Fans and mounted separately on the conveyor frame.

Materials were selected according to the requirement of the design and considered about all the safety issues, maintenance and manufacturing factors. The design includes all the security measures including emergency buttons, button panel box and a tower lamp with buzzer. A touch panel was designed to be mounted on the machine in order to build a human machine interface.

### C. *Control System*

As the control structure of the Automated Ruler Printing Machine, Programmable Logic Controller (PLC) based control system was used along with the sensor inputs, electrical and pneumatic actuators. Human Machine Interface (HMI) was used to input data to the PLC and display data.

The basic structure of the control system can be illustrated as follows.

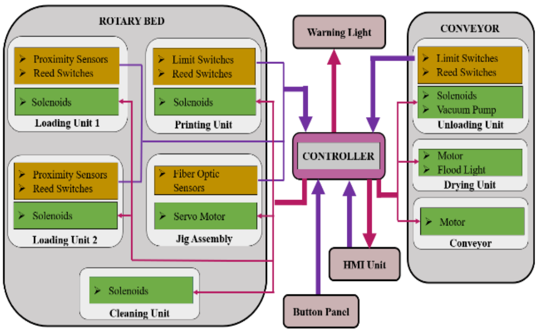

Figure 4. Structure of the Control System

As the microcontroller of the Automatic Ruler Printing Machine, a PLC was used with PLC programming language ladder logic. HMI was used to input data to the PLC and display data. Several sensors such as fiber optics and proximity sensors were used throughout the machine for required phases of the machine.

Most of the actuators were based on the pneumatics and for this several solenoids, pneumatic fittings, suction pads and vacuum pumps were used.

## Results and Discussion

The main aim of this project was to fully automate the function of twelve-inch ruler printing process and most of the project objectives were achieved by doing alterations throughout the project. As mentioned, rotary indexing mechanism was used with four stations and for this design a key bar arrangement was used eliminating the difficulties of using a solid rotary disc. Loading, cleaning, printing and unloading is done at separate stations and all the sub assembly units were designed as separate units for easy fabrication and maintenance activities.

Since some of the basic functions were crucial, they were tested using prototypes prior to final design. By this most of the problems were overcame. By introducing online packing for rulers by using a conveying process, the reduction of work in process and lead times were achieved. Inbuilt drying unit also taken a prominent place since it reduced the dying time and improve production rates during the ruler printing process.

Calculations and simulations were done to optimize the design and analysed the results obtained by the fully automated machine and existing semi-automated ruler printing machine in order to achieve project objectives.

The bottle neck of the process was identified as the time taken to dry the printed rulers , the manual process involved a free air drying technique which on average consumed 15 minutes. The problem of drying time lead to increase in work in progress and lower production rates the use of UV based ink allowed the drying time to be improved to an exposure time of 5 seconds on the running conveyor which in turn improved the production rate.

Comparison for the production rates of prevailing semi automated machine and fully automated machine was done by taking production data for day shift. Accordingly, it was observed that approximately 390 rulers can be produced per hour by using semi automated machine leading approximate production of rulers as 3500 per day. Due to the poor safely issues, production of rulers from existing machine was done only at day time.

By automating the process, it was able to double the production rate by minimizing the drawbacks of the current process. The production of rulers via fully automated machine can be done in both day and night continuously as two shifts due to the improvement of the safety features and production rate was increased by reducing drying time. Accordingly, it was observed that approximately 780 rulers can be produced per hour leading 14000 rulers per day as production can be done in both day and night.

Accordingly, camparison of rate of production of semi automated and fully automated ruler printing machine can be shown as follows.

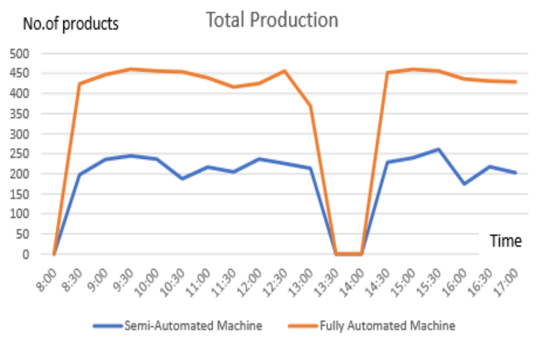


Figure 5. Comparison of Rate of Production

The technique of UV lighting for drying allowed to achieve the expected production rates, further research is required to analyse the cost effectiveness of the process considering the cost for electricity for the high power UV lamp.

The use of high precision cam indexing servo driven gear box allows feedback based deceleration to stop the jig at 90 degree increment of shat angle. This feature combined with sponge based wiping and compressed air supply allows removal of dirt from the unprinted ruler surface with allowed quality print on the surface leading to less defects. Following comparison shows the defect reduction.

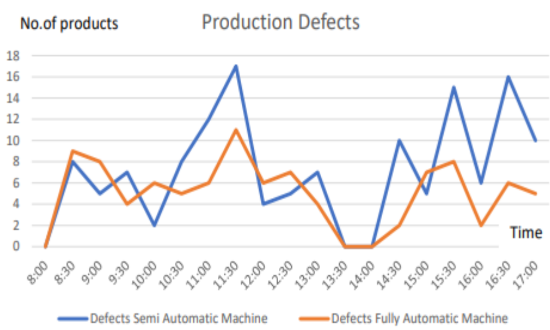


Figure 6. Comparison of Production Defects

Accordingly, by fully automating the ruler printing process, it was able to minimize the production of defects and other drawbacks of the current ruler manufacturing process and improve the production rates which will increase the ability to cope up with customer demand.

## Conclusion

The Automated ruler Printing Machine was designed to overcome the drawbacks of the existing ruler printing process and to increase the productivity. In the design, main focus was to automate the printing process and support the online packing function. As identified in the methodology, worker involvement was reduced by introducing mechanisms to Loading, Cleaning, Printing and Unloading.

First critical function was the loading station with the requirement of four rulers printed at once, two loading stations were used to simplify the loading operation, although this improves the process further designing could ensure the loading of all the four rulers from the same loading station which would improve the overall efficiency of production.

The production of the semi automatic machine was limited to daytime shifts only due to the safety risk involved as operator hand was involved to load and unload the rulers with the new design safety was improved by the use of a loading tray, its is essential to improve the design further to prevent any hazards based on moving parts and contact of human operator further research with qualitative measures would prove improved safety. The defects were reduced based on precision alignment and improved cleaning, end product defects were based on human operator judgement to distinguish defective products, research continued on identifying defects based on scientific method would lead to improvements in quality such as computer vision to compare the products.

Another step taken to optimize the design was, adding adjustments for mechanical mechanisms. Even with the calculations, some practical scenarios cannot be addressed. For the machine, most of the components were selected based on calculations and referring to manufacture's catalogs, suitable components were selected. But in some scenarios, available components were used as per the company's preference.

Calculations and simulation results were used to confirm their suitability. This machine was designed for the long run of the company with improved productivity, efficiency and safety, by correct utilization of the machine, expected output can be obtained.

Major problem identified for further research is to optimize the drying time based on humidity & temperature to prevent sticking of the printed rulers to polythene packaging material , additional data collection method is required to be developed to inspect the sticky surface of the ruler with the polythene to further improve quality of production.

## Acknowledgment

Special thanks goes to staff of Mechanical Engineering Department, Faculty of Engineering of General Sir John Kotelawala Defence University,Ratmalana, Sri Lanka and Atlas Axillia Co.(Pvt) Ltd, Sri Lanka for providing valuable support, facilities and funds for the research work.

## References

Flint, F. C. (1938) 'Apparatus for Decorating Glassware and Other Articles'. Available at: https://patents.google.com/patent/US2160725A/en?oq=2%2C160%2C725+ [Accessed 11 Mar. 2018].

Francois, D. (2009) 'Screen Printer Machine'. doi: 10.1016/j.(73) [Accessed 11 Mar. 2018].

Georg, J. and Wuerzburg, S. (1997) 'Rotary Screen-Printing Machine for Sheet Printing', (19). Available at: https://patents.google.com/patent/US5671671A/en [Accessed 11 Mar. 2018] .

Groover, M. (1980). Automation, Production Systems, and Computer-Integrated Manufacturing. 3rd ed.

Jaffa, D. and Lakes, F. (1983). Cleaning Attachment for Screen Printer Available at: https://patents.google.com/patent/US4389936 [Accessed 11 Mar. 2018].

Kachare, S. A. *et al.* (2016) 'Pneumatic Multicolour Screen Printing Machine', 4(3), pp. 1031–1033. Available at: http://www.ijsrd.com/articles/IJSRDV4I30881.pdf [Accessed 11 Mar. 2018].

Karlyn, W. M. *et al.* (1994) 'Multicolor Printing System for The Silk Screen Printing of Compact Discs'. Available at: https://patents.google.com/patent/US5335594A/en [Accessed 11 Mar. 2018].

Khurmi, R. and Gupta, J. (2005). A textbook of machine design. New Delhi: Eurasia Publishing House.

Pengfei, L. (2010) 'Application of CANopen and Modbus Protocol in Rotary Screen Printing Machine Request Response', pp. 666–669. Available at: https://ieeexplore.ieee.org/document/5555385/ [Accessed 11 Mar. 2018].

Sirvet, E., Whelan, E. and Skrypek, J. (1970). Mandrel Assembly for Continuous Can Printing Available at: https://patents.google.com/patent/US4267771[Accessed 11 Mar. 2018].

SKF-rolling-bearings-catalogue. (2018). [pdf] Available at: http://www.skf.com/binary/77-121486/SKF-rolling-bearings-catalogue.pdf [Accessed 28 May 2018].

Wick, K. (1976) 'Rotary Screen-Printing Machine with Angle and Pressure Adjustable Squeegee'. doi: US005485919A[Accessed 11 Mar. 2018].

## Author Biographies

SS Vitharana graduated from General Sir John Kotelawala Defence University, Ratmalana, Sri Lanka in 2018 and specialized in the field of Mechatronics Engineering. Worked as a Temporary Instructor at Department of Mechanical Engineering, General Sir John Kotelawala Defence University. His research interest include automation, programming and robotics.

WVPP Madhumali graduated from General Sir John Kotelawala Defence University, Ratmalana, Sri Lanka in 2018 and specialized in the field of Mechatronics Engineering. Currently working as a Temporary Instructor at Department of Mechanical Engineering,General Sir John Kotelawala Defence University. Her research interest include automation and control systems.

GATD Herath graduated from General Sir John Kotelawala Defence University, Ratmalana, Sri Lanka in 2018 and specialized in the field of Mechatronics Engineering. Curently working as a Technical Assistant (Executive) at Rinstrum (Pvt) Ltd, Negombo. His research interest include automation, control systems and robotics.

WSP Fernando graduated from University of Moratuwa, Sri Lanka in 2004 and specialized in the field of Computer Science and Engineering and followed M.Phil in 2011 from University of Moratuwa. Currently working as a Senior Lecturer at Department of Mechanical Engineering, General Sir John Kotelawala Defence University. His research interest include computer vision, mathematical optimization and digital signal processing.

DH Marabedda graduated from University of Ruhuna, Sri Lanka in 2011 and specialized in the field of Mechanical and Manufacturing Engineering. Currently working as an Automation Manager at Atlas Aillia Co (Pvt) Ltd, Sri Lanka. His research interest include automation and control systems.