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Automatic Paper Slitter and Rewinding Machine

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Abstract

Nowadays, automation plays a key role in all over the industries. Due to the demand of using paper is growing day by day, efficiency and quality is need to be improved in the process of paper mill. Although, paper making involves the use of several different processes and machines. The slitter-rewinder is an essential part of any paper mill. Unwinding of large, main freshly produced rolls from paper making machine, cutting it into smaller length, and rewinding it to smaller rolls for delivery is the jobof a slitter-rewinder machine. Any issue with the slitter-rewinder, which is one of the production process in the paper mill, will cause entire mill to shut down. This paper explains how the various stages in the process is converting the manually operating rewinding and slitter machine into fully automated rewinding and slitter machine. The basic concept uses load cell based tension controller, nip reliving rider roll using PID proportional valve, HMI, and PLC to carry out the process. The main idea is to automate the process to avoid paper breakage and bring in optimal time management and quality rewinding.

Keywords—Automation, Rewinder, Slitting machine, PLC, HMI, Paper mill.

I. INTRODUCTION

It is a challenging task to increase productivity and efficiency in most of the leading paper mills in Southeast Asia. This makes the paper mills to retrofit its slitter-rewinder by incorporating the latest technology. The main aim of this upgradation is to improve quality of the roll, which improves the machine speed to its maximum level and to eliminate frequent shutdowns. Most of the paper mill manufacturers are running with the drive systems of 25 to 30 years old. As number of components had become obsolete, repairing and maintenance of the drive system in the slitter-rewinder is more expensive and could not be replaced. Existing old hardwiring control and mechanical unit which hold the thyristor assembly for control in the machine shows the signs of failure and breakdown at some points and issues in power modules.

The automatic slitter-rewinder is the most sophisticated machine in mill machinery, with many motors and controls. Tension, which decides the consistency of the paper rolls, is at the core of this machine's operation. To ensure precise slitting, and proper roll density profiles, precise and

consistent forces must be applied in the process. Except for nip power, the output of the drives is largely responsible for the roll's consistency. The winder must operate as a synchronised mechanism, maintaining precise speed-torque control during continuous cyclic operation of stop to full speed and back to zero speed.

The overall objective includes converting the manually operating Rewinding and Slitter machine into fully automated Rewinding and Slitter machine. For automating the process, load cell-based tension controller, NIP reliving Rider roll using PID proportional valve, HMI, and PLC is used.

II. LITERATURE SURVEY

"Design of a paper slitting and rewinding machine for a developing country", Zimbabwe by Tawanda Mushiri et al. [1], discusses how to design an economic slitting and rewinding machine that focuses on small and medium businesses. Present issue is that such machines are very expensive on the market which makes the small and medium business in developing countries cannot afford it.

"Design and Analysis of Paper Cutting Machine works on Geneva Mechanism", by Vijay Kumar et al. [2], conducted a study of mechanism incorporating a Geneva wheel and a gear train to achieve intermittent motion is presented in paper. Position, velocity and acceleration are compared. Reduce extreme jerk of Geneva wheel is used to find the non-circular motion of the gear pair. The Geneva drive is an indexing mechanism that converts continuous motion to intermittent motion, allowing the paper to be moved in-between cutting intervals. It describes the cutting operation using a crank-lever mechanism. The cutter return to its original position by means of spring effect.

"Advanced Paper Cutting Machine using ARM7", by SS Lavhate [3], proposed that the designed system will be an automated smart length measurement device. It includes a rotary encoder, proximity switches, motor, and an embedded design that includes a microcontroller circuit and other components. The device serves as the control circuit for a paper cutting machine that can cut a variety of materials including paper, plastic, thin film, leather, and nonferrous metal slices. The paper cutting industry uses this system and demonstrates the contribution to a low-cost solution in manufacturing.

Patent US4422588A [4], titled "Slitter-rewinder system" a slitter and a drum type rewinder are part of a slitting and rewinding system and method. The core-cutter comprises a tool magazine for storing cores. For severing a selected core into widths according to the setting of the slitter knives, a transversely programmable movable core slitter was provided. The sections of slit core are received by a core transporter, which transports them to the winder drums while also moves the winded roll out of winding position. The paper web severing and adhesive application device cuts the web from the winder and applies adhesive strips to the back's tail and lead corners.

III. METHODOLOGY

Hierarchy processes required for the development of various modules of an Automatic high-speed rewinding and slitter machine. Fig.1 shows the methodology flow chart of the paper slitter rewinder.

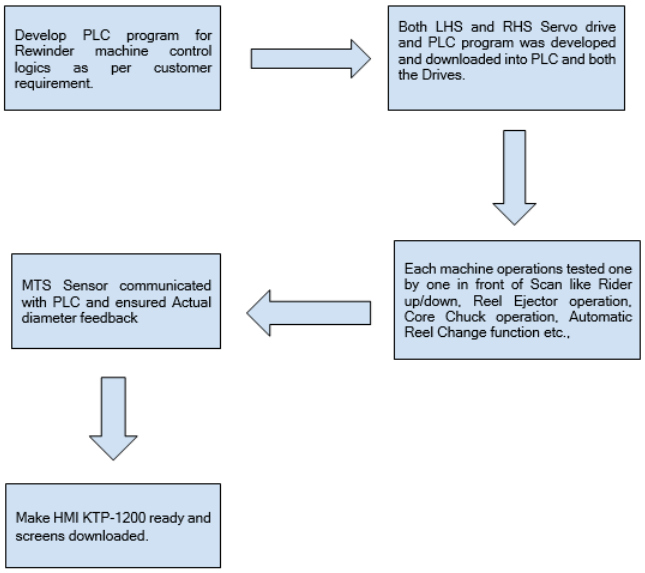

Fig.1. Methodology Flow Chart

Retrofitting of Rewinder-Slitter starts with removing the required PLC panel wirings and connected in spare DI in new control desk via relay board and tested. S7- Profinet communication established in S7-1500 PLC and check all handshaking signals to control the rewinder operation like commands and feedback signals. Switch on the old 6RA70 DC drive and check the operation in no load. Required PLC Program in both S7-1500 PLC was developed and downloaded. HMI Screens modified as per the requirements and downloaded. Rider and Core Chuck operation tested. Paper passed into the machine and check the operation in manual tension control and Rider manual Nip releaving state was done. Run the rewinder in both manual / auto mode and check the operation. All machine side interlocks in PLC program was updated and tested. Machine runs continuous up to 400 MPM and there is no fault observed.

IV. Parts Of Paper Rewinder and Slitter

A. Load cell for tension controller

The load cells on the machine's unwind section were replaced with Mitsubishi Tension Controller LE7-40GU-L modules, which were chosen based on device specifications and it is direct physical contact with frame. Mitsubishi's latest load cells, comes with pre-calibrated for an application, which decreases friction and tension control. Fig.2 shows load cell mounted on a machine.

Fig.2. Load Cell

B. I2P valve

A current to pressure transducer is used to convert a 4 to 20mA analogue signal into a proportional linear pneumatic value of 3 to 15 psi. The function of I2P is to convert an analogue output from a control device into a specific, repeatable pressure value for pneumatic valve control.

An electrical signal from a controller is received form an I2P transducer and generate a proportional output in the pneumatic form for controlling the control valve. The system is attached to the wall and a pipe stand, or valve actuator. They are directly mounted on valve actuator and this mechanism withstand the vibrations. To minimize vibrations, the system is often placed remotely on instrument pipe stands. Fig.3 shows the I2P valve inside the Circuit.

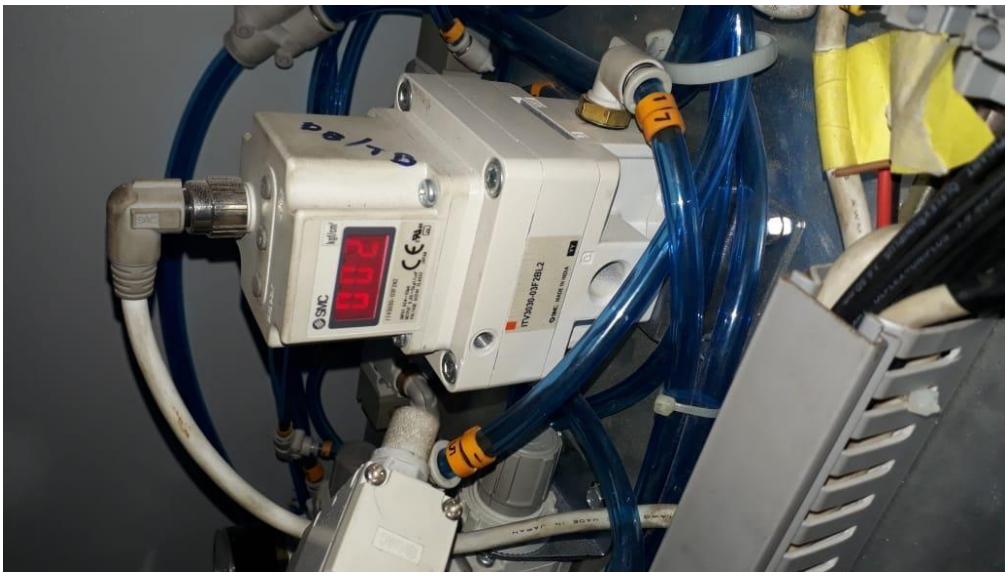

Fig.3. I2P Valve

C. *Pneumatic unwinder brake*

It is important to use processes that ensure process consistency and excellent semi-finished or finished product quality in order to maximize the production cycle. The most important parameter is the web tension. To prevent any material breakage as well as ripples that can cause defects on the final product, it is critical that the correct tension value remains constant in all work phases by using high-quality clutches and brakes. In open or closed loop tension control regulation systems, the brakes and clutches are mounted on roll stands, winders, and unwinders.

Pneumatic brakes are the perfect solution for unwinders, slitters, and rewinder machines – the high torque ratio is needed for effective tension control both during the tensioning process and during emergency stops. In this situation, the pneumatic brakes must operate at lower temperatures in order to maintain continuous web tension control at any line speed while also reducing part wear and dust emissions in the workplace. By meeting these objectives, the brakes lead to a higher degree of environmental compliance and operator protection, as well as an improvement in system performance and a decrease in maintenance times and costs. Fig. 4 shows Unwinder Brake of the unwinder.

Fig.4. Unwinder Brake

D.Master Control via HMI

SIEMENS KTP700 HMI panel screen is developed to optimise the profile and quality of the roll during auto stop, product recipes, numeric and graphical set-points, permissive, complete analysis in conjunction with the drives. SIEMENS KTP700 HMI shown in Fig.5 shows an complete and simple interface that combines the control equipment with drive hardware and results in less complex device with improved performance. It's much simpler to troubleshoot and manage.

Fig.5. HMI Panel

The paper mills have the problem with product length and diameter was solved by the automatic stopping function. Permissive and diagnostic pages helped operators keep the winder running smoothly and cut down on service calls to maintenance. The recipe system made it possible for operations to easily set up orders while maintaining product continuity.

V. WORKING OF SLITTER REWINDING MACHINE

A paper slitter rewinding machine is a retrofitting machine that cuts the main large paper roll into small rolls that can be used for other purposes. Fig. 6 shows basic components of a slitter rewinder of paper machine.

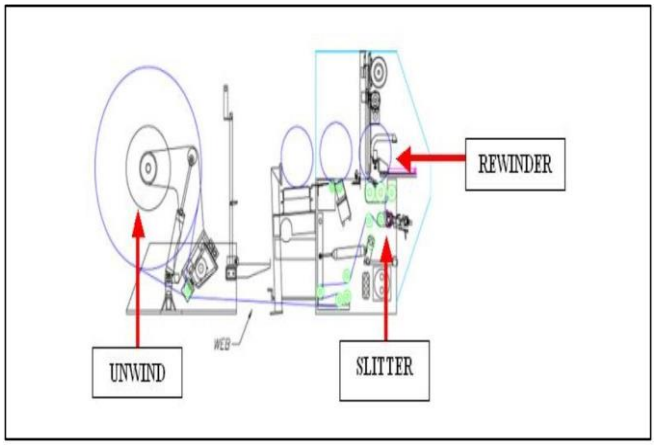

Fig.6. Basic Components of Slitter-Rewinder

The paper slitter rewinding machine consists of:

1) Unwinding stage
2) Slitting stage
3) Rewinding or winding stage

A. Unwinding stage

This stage contains a stand to unwind, which is used to load and secure the main roll of paper. The roll would be held in place by the stand, which causes it to rotate around its central axis. The two extended ends of a shaft are clamped which retain the rolls that runs the entire length of the rolls on bearings in backside stand, or each with mechanical gripping elements on both ends of the roll by inserting two chucks that extends in order to hold it. Big inertial forces are encountered when unwinding heavy rolls at first, which can cut the paper. Guided unwinds are used to brake as required so that the material's precise tension during the process is maintained.

B. *Slitting Stage*

The slitting of webs into several small slits takes place during slitting point. The paper which is unwound is then carried over to a series of spread rollers and slitter head after leaving winding point. The slitter head is used to cut the web. The slitter head contains a series of rotating knives or razors. Depending on unit type, the required width of the slit is set in manual or automatic by adjusting knives position on the slitter head. There are rollers in front of the slitter head that which makes the sheet straight and ensures cuts in good quality.

C. Rewinding Stage

In this stage, rewound of rolls into required diameter of small cores is done in the rewind stand from slitter head. Factors like wound material and roll hardness, influence type of winder that is used in the specified situation. After slitter head, the rollers split the slit parts when they join the winding. It prevents the roll range of the sheet weaving back and forth in-between adjacent rolls.

VI. DESIGN STAGES

A. Surface winder two drum design

Webs line speed are known and it helps in determining the speed of assumed diameter and surface diameter. The calculations of required torque by the electric motor used to run the surface drum was done. The required torque is the product of the surface drum radius and overall tension at the surface of surface drum in the web. As seen under various design phases, losses and other design factors were also taken into account. Fig.7 shows the assembly of drum in retrofitted slitting and rewinding machine.

Fig.7. Drum

B. Slitting system rotary shear design

First, the standard size of 8" diameter bottom knife was chosen. Fig.8 shows the rotary shear of the paper slitting and rewinding machine.

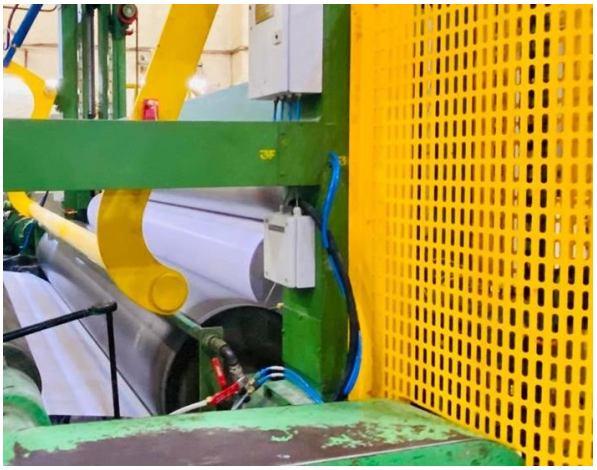

Fig.8. Rotary Shear

Several calculations were performed using this diameter value to decide the appropriate size of top knife to maintain right configurations such as arch movement, penetration depth, and centre distance between the top and bottom knives during normal machine working conditions. When calculating strength needed to move the slitter head, overall force acting on top and bottom knives was considered.

C. Unwind section design

Unwind stage shows design of unwind centre. The motor selection that would drive the unwind stand is done. Fig. 9 shows the unwind stage of slitting and rewinding machine.

Fig.9. Unwind Section

D. Final Assembly

All the component in the machine slitter is assembled with reference to the assembly drawing. Fig.10 shows the final assembly drawing the machine.

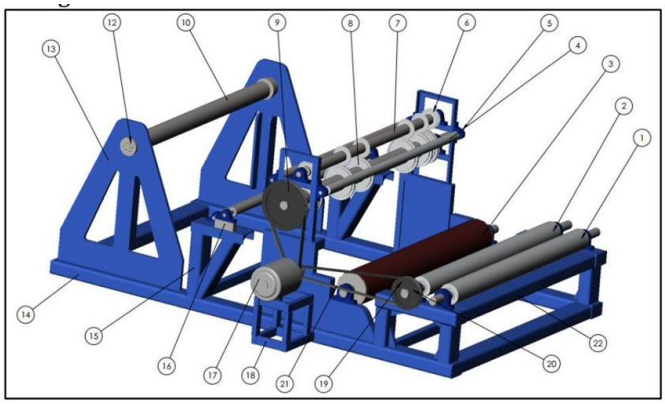

Fig.10 Slitter-Rewinder Assembly

TABLE I. MACHINE COMPONENT OF 3D ASSEMBLY

Part number	Part Name
1, 2	Surface drums
3	Traction roll
4	Straightening roller
5	bearing
6	Top knife
7	Top knife shaft
8	Bottom knife
9	Bottom knife shaft pulley

10	Unwind core
11	Bottom knife shaft
12	Unwind core chuck
13	Unwind stand
14	Main frame base
15	Load cell unit stand
16	Load cell
17	Slitter head/ surface drum electric drive motor
18	Electric motor stand
19 and 20	Surface drum pulley
21	'V' belt
22	Surface winder stand

Table 1 shows the final 3D assembly showing machine components.

E. Selection of Drives

By installation of the 6RA70 DC Drive and V90 AC drives, in conjunction with HMI, high output, top speed performance, improved quality of rolls, less maintenance, and minimum shutdowns can be achieved in paper mill. They have also been able to virtually remove shut downs that occurred due to component failure.

VII. Testing and Implemenation

A. Stress analysis of the bottom knife

In the bottom knife, the highest von Mises tension occurs nearest to the knife is connected to the bottom knife shaft. As a result, the design is safer. Fig. 11 and Fig.12 depicts Von Mises Stress analysis on the top of knife under the condition of static loading.

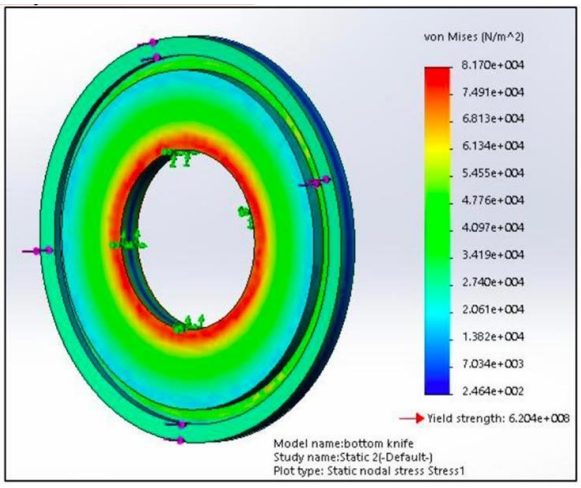

Fig. 11. Stress Analysis Results from Solid works

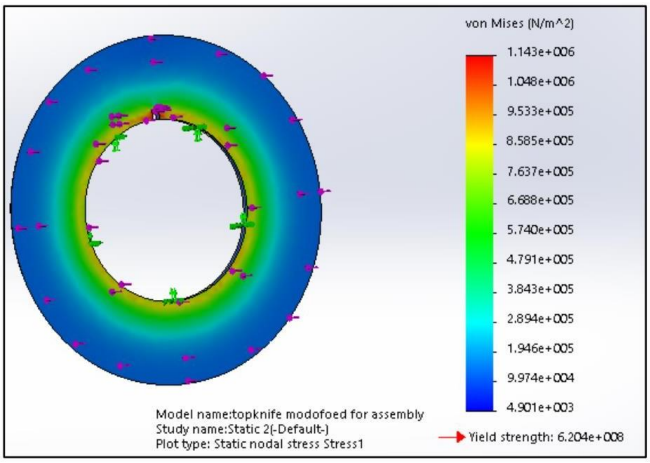

Fig. 12. Stess analysis of Knife

B. Results of Von Mises Stress Analysis

Factor of safety is assumed as N=10, The designed stress is as follows:

$$\sigma_d = \frac{6.204*10^8}{10} = 62.04Mpa.$$

$$\sigma' \leq \sigma_d$$

$$1.143MPa \leq 62.04MPa.$$

Overall, knife's design stress is greater than the von Mises stress. As a result, design is perfect. The result of stress analysis shows that the yield stresses of the components is more than the maximum Von Mises stress in the measured components. As a result, these components will not malfunction under normal operating conditions.

C. Front Control desk

The application program was developed and commissioning was done. The drive and controller software was devleoped, and the panel was as shown Fig.13. After a complete two-weeks of testing, these new equipment within the contingency the mill was installed. The plant was ensured to a seamless transition.

Fig. 13 Control Desk

D. PLC Program

The relay ladder logic program blocks for the following functions of rewinder and slitter machine was developed and implemented. Fig.14, Fig.15 and Fig.16 shows the sample relay ladder logic PLC program of the machine.

Automation_Control_Desk_PR216_Rewinder/PLC_1
[CPU 1511-1 PN] / Program blocks include:

- Auto_Reel_Change [FC8
- Interlocks [FC1]
- Core_Chuck [FC5]
- Curve1_FC [FC18
- Curve2_FC [FC19
- Curve3_FC [FC21]
- Curve4_FC [FC21]
- Curve5_FC [FC21]
- Length_Calculation [FC10]
- LHS_Core_Chuck [FC6]
- LINE_SPEED_GEN [FC15]
- MOTOR SPEED CALC [FC20]
- Moving_Parts_MC [FC3]
- MTS [FC9]
- RCV_DATA_FROM_S7300_PLC [FC12]
- REWINDER_LOGIC [FC13]

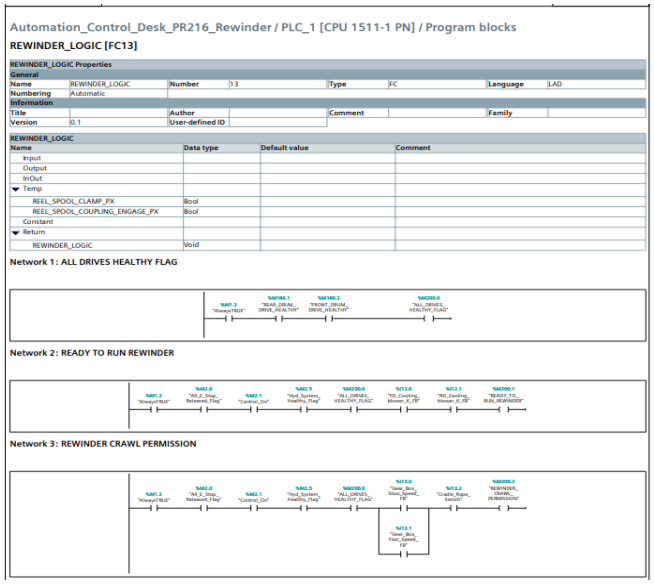

Fig. 13. PLC Sample Program of Rewinder

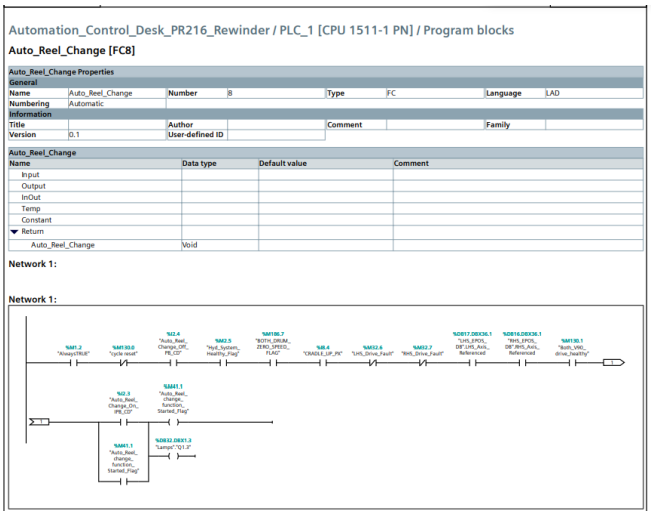

Fig. 15. PLC Sample Program of Auto Reel Change

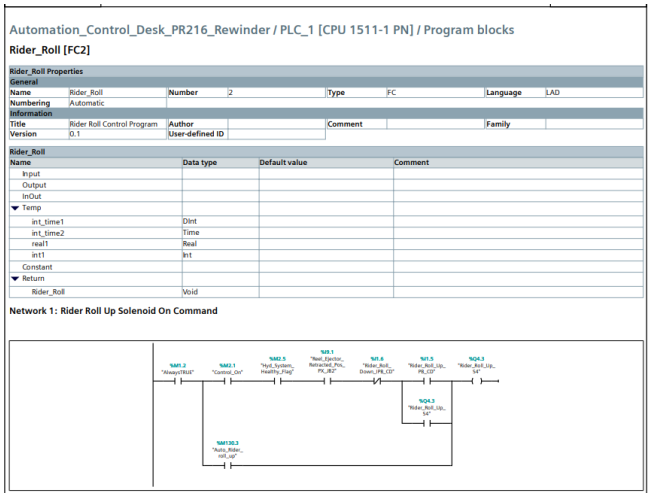

Fig. 15. PLC Sample Program of Rider Roll

VIII. CONCLUSION

The paper slitter-rewinder machine was retrofitted to run automatically and it was implemented. The Control panel was build. The drive and machine process PLC program, front end control panel was developed and installed. The complete retrofitting machine was interfaced with control panel and installed successfully. The machine could be run to cut paper ranges from 1189mm to 40mm with any constraints.

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