# Development of PLC Based Control System for Automatic Shearing Machine

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*Abstract*— Our everyday life comprises of an endless list of commodities and products which are made up of metal or metallic components. Metal is used in a wide range application from house wiring to the transport facilities that we use every day. Of all these day-to-day goods, the use of metallic sheets is proportionally high. The examples of their use include our kitchens, bathrooms, drawing rooms, study rooms, furniture, decoration, doors etc. To mold these sheets as per the requirement of the individual product requires skill and to put this skill to use, some machinery is required. There is a wide range of machinery used to mold these materials; change their shape, dimensions, surface finish etc. In order to put them through these changes, they are required to be cut to the exact dimensions as per application. A Shearing Machine is used for this purpose. The machine is a mechanical arrangement so as to provide mechanical advantage and reduce effort of the operator in cutting the sheets. Adjusting the machine for cutting a particular thickness of sheet is a tedious task and prone to error which results in job defects. So, a solution is required to overcome this issue. We hereby propose to build a PLC Based Control System for such an Automatic Shearing Machine. Use of PC based automation is not required for this application as it do not require intense calculations and complexity. So, we suggest going for PLC based automation for the same. This will reduce the number of control components thus reducing the data interaction time. After implementation, the results obtained are – the cycle time of the entire process is reduced; the system boots in 14 seconds, setting time is as low as 4 seconds and as high as 6 seconds as compared to 12 seconds in the earlier configuration. The HMI has been provided with the functions useful for the current configuration of the machine and thus is more acceptable to the operator as it creates lesser confusion. The cost of the new control components configuration is 40.56% of the cost of previous configuration.

***Key words:*** HMI, PLC

## I. Introduction

Our everyday life comprises of an endless list of commodities or/and products which are made up of metal or metallic components. From house wiring to the transport facilities that we use everyday include the use of metal for proper implementation. Of all these day-to-day goods, the use of metallic sheets has a good proportion. The examples of their use include but not limits to our kitchens, bathrooms, drawing rooms, study rooms, furniture, decoration, doors etc. To mold these sheets as per the requirement of the individual product requires skill. And to put this skill to use, some machinery is required. There is a wide range of machineries used to mold these materials; change their shape, dimensions, surface finish etc. In order to put them through these changes, they are required to be cut to the exact dimensions as per application. There are various metal cutting processes such as – Plasma Cutting, Water Jet Machining, Punching, Laser Cutting, Shearing and more. We shall be concerned with shearing process hereon.

## II. Shearing

Shearing, also known as die cutting, is a process which cuts stock without the formation of chips or the use of burning or melting. In strict technical terms, the process of "shearing" involves the use of straight cutting blades; and, if the cutting blades are curved then the process is considered a "shearing-type operation." The most commonly sheared materials are in the form of sheet metal or plates; however rods can also be sheared. It is used in metalworking and also with paper and plastics.

## III. Shearing Machine

We shall discuss about the working principle of a shearing machine. A punch (or moving blade) is used to push the work-piece against the die (or fixed blade), which is fixed. Usually the clearance between the two is 5 to 40% of the thickness of the material, but dependent on the material. Clearance is defined as the separation between the blades, measured at the point where the cutting action takes place and perpendicular to the direction of blade movement. It affects the finish of the cut (burr) and the machine's power consumption. This causes the material to experience highly localized shear stresses between the punch and die. The material will then fail when the punch has moved 15 to 60% the thickness of the material, because the shear stresses are greater than the shear strength of the material and the remainder of the material is torn. Two distinct sections can be seen on a sheared work-piece, the first part being plastic deformation and the second being fractured. Because of normal non-homogeneities in materials and inconsistencies in clearance between the punch and die, the shearing action does not occur in a uniform manner. The fracture will begin at the weakest point and progress to the next weakest point until the entire work-piece has been sheared; this is what causes the rough edge. The rough edge can be reduced if the work-piece is clamped from the top with a die cushion. Above a certain pressure the fracture zone can be completely eliminated. However, the sheared edge of the work-piece will usually experience work-hardening and cracking. If the work-piece has too much clearance, then it may experience roll-over or heavy burring.

There are various shearing machine/tools available for executing operations. Of these, few are discussed in brief here. The shearing machines and mechanisms are – Alligator Shear, Bench Shear, Guillotine, Snips etc. We shall focus on the guillotine type shearing machine in this paper.

 

## IV. GUILLOTINES

Guillotine is also called a squaring shear or power shear. The machine may be foot powered (or less commonly hand powered), or mechanically or hydraulically powered. It works by first clamping the material with a ram. A moving blade then comes down across a fixed blade to shear the material. For larger shears the moving blade may be set on an angle or "rocked" in order to shear the material progressively from one side to the other; this angle is referred to as the shear angle. This decreases the amount of force required, but increases the stroke. A 5 degree shear angle decreases the force by about 20%. The amount of energy used is still the same. The moving blade may also be inclined 0.5 to 2.5°, this angle is called the rake angle, to keep the material from becoming wedged between the blades, however it compromises the square shape of the edge. As far as equipment is concerned, the machine consists of a shear table, work-holding device, upper and lower blades, and a gauging device. The shear table is the part of the machinery that the work-piece rests on while being sheared. The work-holding device is used to hold the work-piece in place and keep it from moving or buckling while under stress. The upper and lower blades are the piece of machinery that actually do the cutting, while the gauging device is used to ensure that the work-piece is being cut where it is supposed to be. A guillotine is shown in Figure1.

Fig. 1: Guillotine Machine

## V. PLC

A programmable logic controller, PLC, or programmable controller is a digital computer used for automation of typically industrial electromechanical processes, such as control of machinery on factory assembly lines, amusement rides, or light fixtures. PLCs are used in many machines, in many industries. PLCs are designed for multiple arrangements of digital and analog inputs and outputs, extended temperature ranges, immunity to electrical noise, and resistance to vibration and impact. Programs to control machine operation are typically stored in battery-backed-up or non-volatile memory. A PLC is an example of a "hard" real-time system since output results must be produced in response to input conditions within a limited time, otherwise unintended operation will result. Before the PLC, control, sequencing, and safety interlock logic for manufacturing automobiles was mainly composed of relays, cam timers, drum sequencers, and dedicated closed-loop controllers. Since these could number in the hundreds or even thousands, the process for updating such facilities for the yearly model change-over was very time consuming and expensive, as electricians needed to individually rewire the relays to change their operational characteristics.

## VI. PLC V/S INDUSTRIAL PC

Following points were considered to opt for a PLC Based Control System:

1) An Industrial-PC(IPC) requires the use of an Operating System which may take 1 to 1.5 minutes to boot, whereas, start up time of a PLC is only few seconds.
2) Further, once the boot is complete, the machine application is executed from the PC which further takes few seconds to load all the peripheral data into memory, whereas, in case of a PLC, it does during the boot time.
3) The IPC requires a I/O Card coupler to connect to the peripherals, thus requiring extra processing time for data interactions. A PLC itself is the logic executor and thus the processing time for data interaction is reduced at the back-end due to reduced components for data exchange.
4) IPC has a better processing speed, but its speed is limited by the I/O coupler's speed and hence a lag in data exchange is observed. PLC is not limited by any other device as it itself is the processor of the system and can perform at its peak speed.
5) The components required by a IPC might not work on the same power supply and need a different supply, whereas, in the PLCs, all cards are at the same potential as the PLC.
6) Cost of an IPC is as high as few lakhs and require other support devices to function properly, the cost of PLC is comparatively low (around a lakh) with reduced number of components.

PLC based control System was decided in view of the above points. Also, such high precision calculations are not part of our application, so we may switch to PLC Control as compared to the earlier PC based system. Some components were reduced as well to further reduce the time lag in updating settings.

## VII. LITERATURE REVIEW

Regarding the shearing machine in focus, much work has been done before and probably some further possibility in this field might still exist. The work in this field commenced during the end of 19th century, when researchers were working on a prototype for a machine which would reduce the human effort in cutting/ parting blocks from high thickness parent block.[12]Wiley Brent stated in his publication titled "Characteristics of motors for large shears" in the year 1909 the importance of the flywheels in the design of that which would store the energy of the driving motor at peak speed and would deliver a lot of energy within a range of 1.5 to 2 seconds time for performing the cutting stroke. The flywheel apart from storing the motors energy also served the purpose of a safety device which would absorb the shock during the full load and no load transition during cutting and release stroke complete cycle.

Guillotines, the title given this specific purpose machine, gained a significant role in industrial application for sheet cutting and certain standards were set for attaining safe and precise operation for these machine. [2]Australian standard for Guillotines with the title “The Guarding and Safe Use of Metal and Paper Cutting Guillotines” was accepted by the Council of The Standards Association of Australia on June 7,1976 and was published on March 1, 1977.

Later in the late 80’s, [13]Hancock T.M. through his paper “Integration of Design, Planning, and Manufacturing Subsystems in Sheet Metal Processing” stated the successful demonstration of a prototype shearing machine integrated with Computer Integrated Manufacturing functions and achieve fully automatic control between all the operation oriented components successfully. A generative computer-aided process-planning module operates directly on CAD exchange files, supplying part process information to a master production compiler. The compiler, in turn, combines small parts into standard sheet metal sizes and then issues efficient NC process instructions to a punch-and-shear machine series.

The Automatic shearing machine here is an example of a One-Dimensional Cutting Problem. The two-dimensional cutting problem is the problem of cutting a single plane rectangle into a number of rectangle pieces of given sizes and values so as to maximize the total value of pieces cut. Most of the previous approaches to tackle this problem are based on dynamic programming. [9]Adel ‘Torkaman Rahmani and Norihilio Ono have proposed in their paper titled “An Evolutionary Approach to Two-Dimensional Guillotine Cutting Problem” a binary tree representation to encode the problem space together with some genetic operators to manipulate such structures. A number of test problems, including a real-world problem, have been used to illustrate the computational performance of their algorithm. Their paper deals with the execution of one-dimensional cutting guillotines, their implementation and issues. [10] Wang Li et al have discussed in their paper “The Research and Realization of Algorithms for Guillotine Rectangle Cutting Stock Problem” the algorithm for a moving blade cutting machine as rectangular block cutting method problem. The cutting stock is the problem which the machining, wood processing, glass processing, construction and otherwood processing, glass processing, construction and other companies are often faced in actual production. From raw material shape point of view, cutting stock problem can be divided into one-dimensional, two-dimensional, and three dimensional cutting. Whether cutting is one-dimensional or two-dimensional, should be done according to some predetermined way, or as cutting scheme, for production. [6] Mr. Shubhkumar M Bhandari has discussed in his article “Methodology of Special Purpose Sheet Cutting Machine” about reasonable cutting scheme that can reduce resource consumption, reduce production costs and improve efficiency.

The shearing operation is a single point cutting operation observed between two blades which unite at a point to perform the cutting operation. For a particular thickness given, there is a set of blade angle and blade clearance, which, if not met, then may result in burrs, breakage of material, bending of material or even damage to the blade of machine. The set of shearing angle and blade clearance differs for different materials as discussed by [1]Dr.V.K.Jain from IIT Kanpur in his paper published in Quarterly Journal of Engineering and Technology (1974).

A solution is to use a high capacity mechanical shearing machine. But, then again, setting the machine for a particular thickness of sheet metal is itself a time consuming and irksome task and at the same time prone to error. At such an implementation, an automatic shearing machine comes into picture. The only requirement for such a machine is, that the operator would enter the thickness of the sheet to be cut into the machine, and the machine would set the blade angle and blade clearance automatically thus saving a lot of delay in production.

The machine should also follow the safety norms laid down by [2]Australian Standards’ published Standard protocol “Code of practice for the guarding and safe use of metal and paper cutting guillotines” in March, 1977, which is a base for standards for Guillotines machines world-wide. The worker safety is of utmost importance in industries. The code is said to have norms such as providing mountings to avoid body parts getting trapped between blade or clamp and material being processed.

## VIII. MODERN PLC

A programmable logic controller, PLC, or programmable controller is a digital computer used for automation of typically industrial electromechanical processes, such as control of machinery on factory assembly lines, amusement rides, or light fixtures. [11]W. Bolton has emphasized the importance of PLCs in industrial Automation in his publication in ninth edition of Newnes with title “Programmable Logic Controllers”. PLCs are used in many machines, in many industries. PLCs are designed for multiple arrangements of digital and analog inputs and outputs, extended temperature ranges, immunity to electrical noise, and resistance to vibration and impact. Programs to control machine operation are typically stored in battery-backed-up or non-volatile memory. A PLC is an example of a "hard" real-time system since output results must be produced in response to input conditions within a limited time, otherwise unintended operation will result.

Before the PLC, control, sequencing, and safety interlock logic for manufacturing automobiles was mainly composed of relays, cam timers, drum sequencers, and dedicated closed-loop controllers. Since these could number in the hundreds or even thousands, the process for updating such facilities for the yearly model change-over was very time consuming and expensive, as electricians needed to individually rewire the relays to change their operational characteristics.

In 1968 GM Hydra-Matic (the automatic transmission division of General Motors) issued a request for proposals for an electronic replacement for hard-wired relay systems based on a white paper written by engineer Edward R. Clark. The winning proposal came from Bedford Associates of Bedford, Massachusetts. The first PLC, designated the 084 because it was Bedford Associates' eighty-fourth project, was the result. Bedford Associates started a new company dedicated to developing, manufacturing, selling, and servicing this new product: Modicon, which stood for MOdular DIgital CONtroller. One of the people who worked on that project was Dick Morley, who is considered to be the "father" of the PLC. The

 

Modicon brand was sold in 1977 to Gould Electronics, later acquired by German Company AEG, and then by French Schneider Electric, the current owner.

One of the very first 084 models built is now on display at Modicon's headquarters in North Andover, Massachusetts. It was presented to Modicon by GM, when the unit was retired after nearly twenty years of uninterrupted service. Modicon used the 84 moniker at the end of its product range until the 984 made its appearance.

Early PLCs were designed to replace relay logic systems. These PLCs were programmed in "ladder logic", which strongly resembles a schematic diagram of relay logic. This program notation was chosen to reduce training demands for the existing technicians. Other early PLCs used a form of instruction list programming, based on a stack-based logic solver.

Modern PLCs can be programmed in a variety of ways, from the relay-derived ladder logic to programming languages such as specially adapted dialects of BASIC and C. Another method is state logic, a very high-level programming language designed to program PLCs based on state transition diagrams.

Many early PLCs did not have accompanying programming terminals that were capable of graphical representation of the logic, and so the logic was instead represented as a series of logic expressions in some version of Boolean format, similar to Boolean algebra. As programming terminals evolved, it became more common for ladder logic to be used, for the aforementioned reasons and because it was a familiar format used for electromechanical control panels. Newer formats such as state logic and Function Block (which is similar to the way logic is depicted when using digital integrated logic circuits) exist, but they are still not as popular as ladder logic. A primary reason for this is that PLCs solve the logic in a predictable and repeating sequence, and ladder logic allows the programmer (the person writing the logic) to see any issues with the timing of the logic sequence more easily than would be possible in other formats.

## IX. PROGRAMMING STANDARD – IEC61131-3

IEC 61131 is a well accepted open international standard for Programmable Logic Controllers and was first published in December 1993 by IEC (International Electro-technical Commission). We shall be using IEC 61131-3, i.e., part 3 of IEC 61131 standards to meet our goal for programming these machines.

The recent (third) edition was published in February 2013. Part 3 of IEC 61131 deals with programming languages and defines two graphical and two textual PLC programming language standards:

– Ladder diagram (LD), graphical
– Function block diagram (FBD), graphical
– Structured text (ST), textual
– Instruction list (IL), textual
– Sequential function chart (SFC), has elements to organize programs for sequential and parallel control processing.
– Continuous Function Chart (CFC). This language is an extension to the IEC 61131-3 standard, which gives free positioning of graphic elements.

We shall be dealing with Ladder Diagram in our work and hence shall focus on the same.

## X. LADDER DIAGRAM

Ladder logic was originally a written method to document the design and construction of relay racks as used in manufacturing and process control. Each device in the relay rack would be represented by a symbol on the ladder diagram with connections between those devices shown. In addition, other items external to the relay rack such as pumps, heaters, and so forth would also be shown on the ladder diagram. [7]Edward W. Kamen, have discussed in his publication “Ladder Logic Diagrams and PLC Implementations” about the evolution of Ladder Logic. Ladder logic has evolved into a programming language that represents a program by a graphical diagram based on the circuit diagrams of relay logic hardware. Ladder logic is used to develop software for programmable logic controllers (PLCs) used in industrial control applications. The name is based on the observation that programs in this language resemble ladders, with two vertical rails and a series of horizontal rungs between them. While ladder diagrams were once the only available notation for recording programmable controller programs, today other forms are standardized in IEC 61131-3.

## XI. BLOCK DIAGRAM OF MACHINE

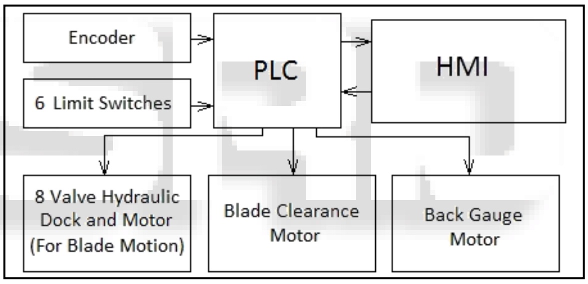


Fig. 2: Block Diagram of Machine

## XII. LOGIC FLOW CHARTS

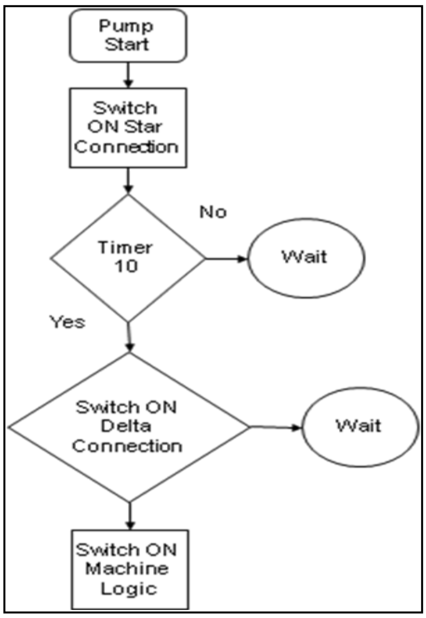


Fig. 3: Machine Start-Up Logic

The logic here describes the electrical connections of the machine which states that when the hydraulic motor will be switched ON, it will first start using the contactor for star connection. This contactor is latched with a Timer Relay which switches the Delta connection contactor ON and switch the earlier one OFF. Once the Delta Timer is switched ON, an input from the NO element of the contactor is given to the PLC check for Delta contactor. If this gives a high input to PLC, the PLC logic will execute or else none of the Logic Rungs will be executed.

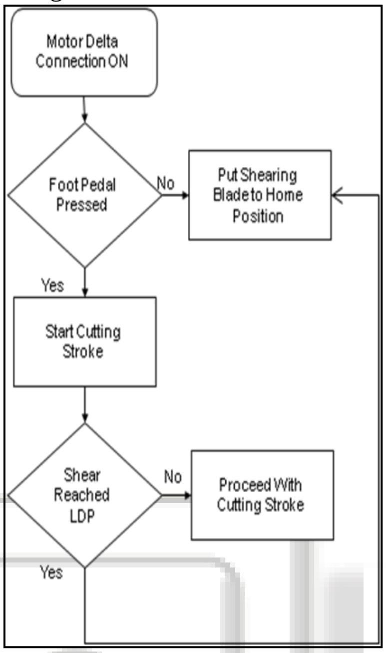


Fig. 4: Stroke Logic

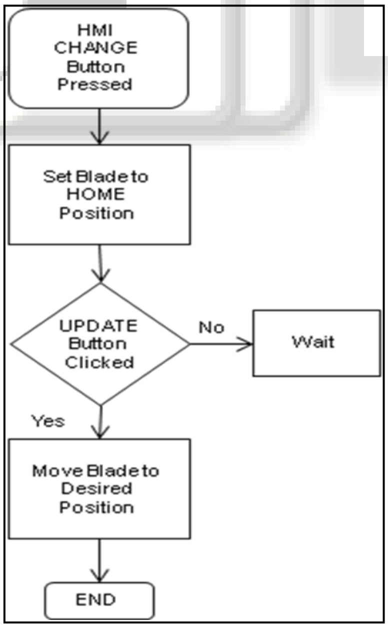


Fig. 5: Blade Clearance Updation Logic

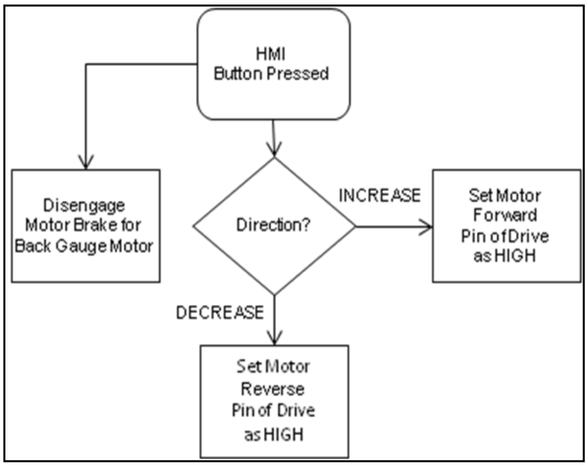


Fig. 6: Back Gauge Motor Logic

## XIII. SCHEMATIC DIAGRAM FOR HYDRAULIC CONTROL

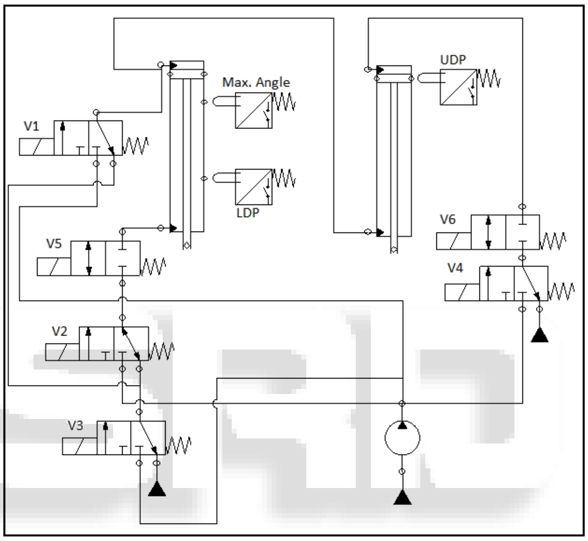


Fig. 7: Mechanism for Executing Stroke and Angle Change

The Block Diagram above illustrates the working mechanism of cutting stroke of the shearing blade. It also explains the mechanism for angle change. The adjoining diagram illustrates the logic used for the execution of the mechanism.

There are various variables used in this logic and are explained below:

- Valves - V1, V2, V3, V4, V5, V6
- Valves involved for cutting stroke – V4 and V6
- Valves involved for cutting stroke – V3, V5 and V6
- Valves involved for increasing angle – V2 and V5
- Valves involved for decreasing angle – V1 and V5

 

## XIV. METHODOLOGY

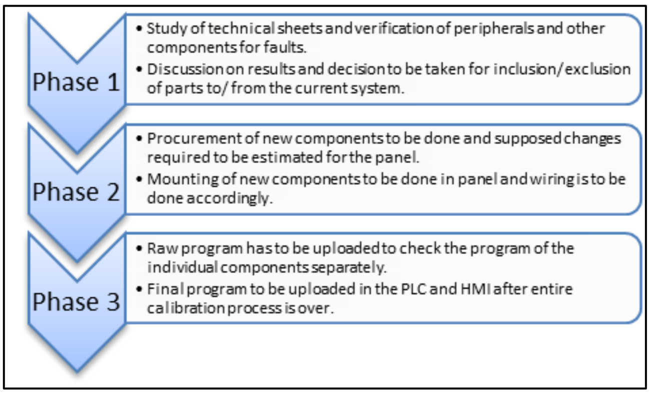


Fig. 8:

## XV. EXPERIMENTAL DATA

| S.No | Angle | Actual Data | Approximated Value Decided |
|---|---|---|---|
| 1 | Average time taken by blade to move from minimum angle to maximum angle and vice-versa. | 4765ms | 4500ms |
| 3 | Value at 1° angle | 4765ms | 4500ms |
| 4 | Value at 2° angle | 3565ms | 3375ms |
| 5 | Value at 3° angle | 2400ms | 2250ms |
| 6 | Value at 4° angle | 1423ms | 1125ms |
| 7 | Value at 5° angle | 400ms | 0ms |

Table 1: Timer Values to Set Angle Position

| Serial No. | Field / Value | Value |
|---|---|---|
| 1 | Minimum clearance required | 0.2mm (for 2mm thick sheet) |
| 2 | Maximum clearance required | 2mm (for 20mm thick sheet) |
| 3 | Time gap between 0.2mm to 2.0mm | 6000ms |
| Clearance | | Timer Value |
| 4 | 0.2mm | 3000ms |
| 5 | 0.3mm | 3710ms |
| 6 | 0.4mm | 3800ms |
| 7 | 0.5mm | 3830ms |
| 8 | 0.6mm | 4000ms |
| 9 | 0.7mm | 4070ms |
| 10 | 0.8mm | 4220ms |
| 11 | 0.9mm | 4350ms |
| 12 | 1.0mm | Default,4530ms |
| 13 | 1.1mm | 4650ms |
| 14 | 1.2mm | 4800ms |
| 15 | 1.3mm | 4900ms |
| 16 | 1.4mm | 5070ms |
| 17 | 1.5mm | 5230ms |
| 18 | 1.6mm | 5320ms |
| 19 | 1.7mm | 5480ms |
| 20 | 1.8mm | 5650ms |
| 21 | 1.9mm | 5800ms |
| 22 | 2.0mm | 6000ms |

Table 2: Blade Clearance Data Taking Limit Switch as Reference

| | |
|---|---|
| Minimum Back Gauge Length | 70mm |
| Maximum Back Gauge Length | 1070mm |
| Difference Between Maximum and Minimum Position | 1000mm |
| Average Pulse Counts From Encoder During Travel of Back Gauge From Maximum to Minimum position | 19999 |
| Average Pulse Counts For 1mm | 19.999 |
| Approximating Pulse Counts From Encoder During Travel of Back Gauge From Maximum to Minimum position | 20000 |
| Approximate Pulse Counts For 1mm | 20 |
| Variable For Back Gauge Length (in mm) | BGL |
| Limit Deciding Formula | (BGL – 70) X 20 |

Table 3: Encoder Data for Back Gauge Operation

## XVI. RESULTS

1) The machine was successfully installed with the PLC Based System made
2) The startup time of the system was reduced
3) The machine takes a minimum of 4 seconds to acquire new given settings and a maximum of 6 seconds.

## XVII. FUTURE WORK

Though, the machine ready for production, is working fine. But still there exist some scope of further automation to be included in the system as discussed below:

1) The machine may be provided with an automatic feeder mechanism. The mechanism can itself feed the machine continuously with the raw sheet from inventory and reduce delay time. The Back Gauge can easily be removed from the machine in this case.
2) An automatic conveyer might prove to be useful in carrying the processed material to the next required station on the production floor thereby reducing the material handling lead time in the process.
3) The major problem that still exists in this machine arises after grinding of the blade and bed. The clearance changes once the blades are grinded. This clearance has to be manually adjusted using 18 Nos. 22mm Allen bolts fixed onto the fixed blade that is a part of machine bed. Since, this process is done manually; there are high risks of inaccuracy in the same. For this, an automatic machine bed calibrator maybe installed which would adjust the blade clearance with much precision.
4) Also, the blade has to be taken off the machine for grinding. An onboard grinding mechanism will reduce the lead time of separating the blade from machine and would grind the blade without it being needed to be detached from the machine.

 

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