Advanced Measuring System

Niculae F. Mihai, Jin De Guillaume, Kartick K. Sivasubramanian, Hadi M.Faour

***Abstract*—The proposed measuring system is a practical method of measuring linear objects, straight or angular, of variable length, and with great precision. The system uses a digital measuring system, consisting of a motor connected to a stopper that can be moved to the required cutting position, a mechanical movement system consisting of a screw and ball nut and a locking device with a rotary offset. The electronic system consists of a Human Machine Interface (HMI) data input, an electronic measuring controller, and a servo motor with an encoder for high precision distance measurement. The whole system is coordinated by software which allows for several measurement options: in inches, illustrated with either decimals or fractions, or in millimeters. The user input and stopper position are displayed in real time. The device facilitates the adjustment of speed and acceleration parameters. Additionally, the offset dimensions can vary according to user-defined lengths. The graphical interface is very user-friendly and consists of 5 pages for various settings and display of information.**

***Index Terms*— Controller, digital measuring, high precision, human Machine Interface,**

I. INTRODUCTION

In the manufacturing industry or in the construction industry, the measurement of cutting objects, regardless of the material: wood, plastic, metal, is done manually, in most cases. Manual measurement can cause errors and a longer measurement time. These two inconveniences have been eliminated by our proposal. In addition, the system can calculate lengths and angles for cuts at any desired angle. This system has been devised for precise measurements with low production costs, all the while minimizing measurement length constraints. Several methods for precise measurements already exist [1] [2], but none meet the advantages provided by this system. This system can be incorporated into many different types of machines used to cut wood, plastic, aluminum, or metal. It can be used to measure lengths and can provide options for user-specified angled cutting. By varying the external offset (position of saw), it can cut up to any desired length. By default, the measurement size is 8 feet, with an optional 30 inch constructive offset made from a precise rotary lever mounted on the slider translation axis.

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II. MECHANICAL TRANSMISSION

The mechanical structure is composed of:

- *mechanical coupling*
- *ball nuts*
- *ball screw*
- *motor*
- *flange*
- *slider*
- *rotary offset w/ stopper*
- *bearings*

The role of the *mechanical coupling* is to take the movement of the electric motor and transmit it with minimal backlash to the *ball screw*. The transmission ratio between the *motor* and the *ball screw* is 1:1. The *ball screw* is fixed between two bearings with the *mechanical coupling* at one end that connects to the *motor*. The *bearings* are supported by the *flanges*.

The rotational movement of the *ball screw* drives the *ball nut* linearly. The flange of the *ball nut* is attached to the *slider*. The *slider* is guided by special plastic sliding systems along the shape of the extruded aluminum profile, ensuring minimal friction.

The *slider* has a bracket for mounting the *rotary offset*, which allows it to be fixed in two different horizontal positions: 0° and 180°. There are two possibilities: zero offset when the *rotary lever* is mounted at 0°, and an offset of 30 inches when the *rotary lever* is mounted at 180°. Fig. 1 shows all the mechanical parts and Table 1 lists the materials used and the quantity of each material.

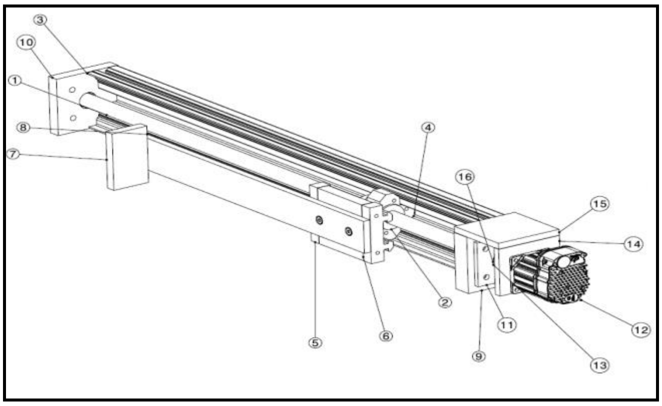

Fig. 1. 3D drawing of measuring device with numbered labels (refer to Table 1)

TABLE I: BILL OF MATERIALS

No.	Part name	Quantity
1	Ball screw	1
2	Ball nut	1
3	Profile	1
4	Flange	1
5	Plastic slider	2
6	Plate	1

7	Offset stopper	2
8	Rotating plate	2
9	Profile plate double bearing	1
10	Profile plate	1
11	Face plate front	2
12	Motor	1
13	Coupler	1
14	Motor flange connection	1
15	Base l-bracket	1
16	Bearing	3

III. ELECTRIC DRIVE AND CONTROL SYSTEM

The drive is carried out with a direct current electric motor, which is a brushless servo motor fixed on the extruded aluminum profile. The movement is incremental and is measured with an electromagnetic encoder with a resolution of 6400 ppr.

The electric motor is controlled by a servo drive, which receives information from an axis controller. Different parameters related to the electric drive system like the velocity, acceleration and the units can be set by the user in the “options” page of the Human Machine Interface (HMI) (Fig. 5).

The control system consists of 3 main components:

- the software component, which allows the setting of the zero position, according to the client's wishes, with any desired measurement offset;
- electronic hardware component, which allows the movement of the cursor with the help of the electric motor and the controller;
- the mechanical component, composed of systems for transmitting and guiding the cursor movement.

The detailed description of the system elements is presented in fig. 1 and in table I.

The role of the HMI is to allow the user to choose the unit of measurement (metric or imperial), establish the acceleration and speed of the cursor, enter the measurement size in different formats, and calibrate.

The role of the electronic controller is to process the information received from the HMI and to then transmit it to the motor controller.

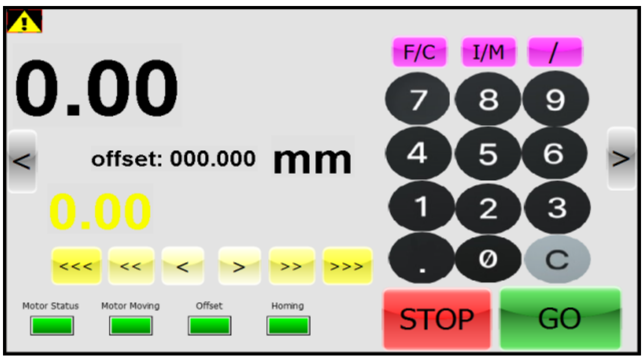

Fig. 2. GUI - home page

The role of the motor controller is to establish the position and speed loop, as well as to ensure movement to the position commanded through the controller by the user. It reads the encoder in real time and controls movement of the motor in the correct direction and with the necessary precision, ensuring minimal errors. It also allows the system to make corrections and eliminate positioning errors.

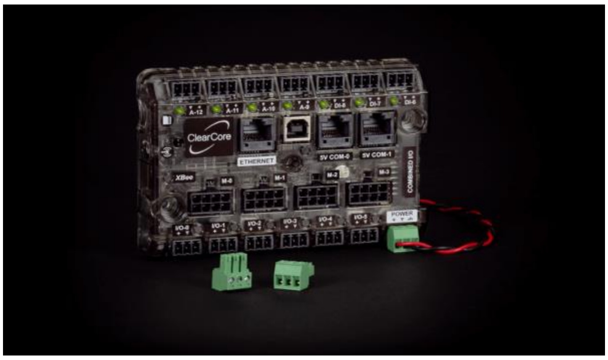

Fig. 3. ClearCore - Industrial motion and I/O controller [3]

The electric motor is a direct current, brushless motor and its role is to turn the ball screw, which further drives the nut and the slider connected to it. The motor must be well calculated and tuned for the mechanical structure, in order to ensure the necessary torque for the mechanical drive. It is fixed by a flange on the bearing support module at the end of the aluminum profile (Fig. 4). [4]

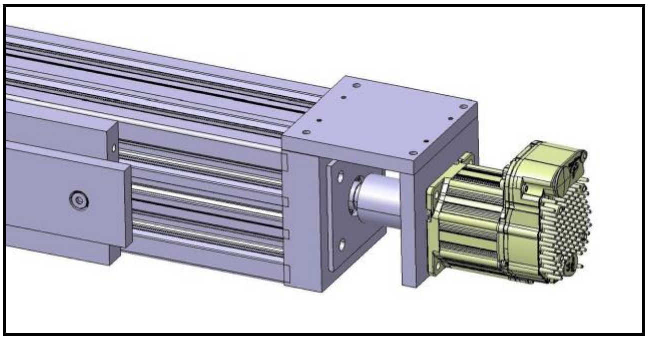

Fig. 4. 3D model of connection between motor, coupler and ball screw

The encoder has 6400 increments per rotation. It allows for a measurement accuracy of upto 0.003 mm.

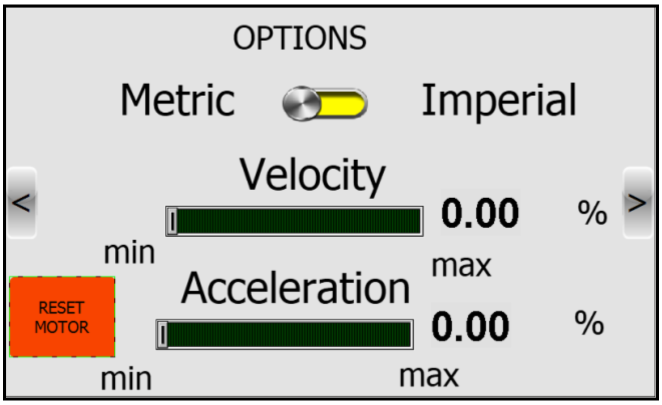

Fig. 5. GUI - Options page

IV. OPERATING MODE

The measuring system can be mounted on any cutting machine with a rotation system on the cutting axis. The cutting machine can cut straight or at angles up to ± 45 degrees. The measuring system is installed on the table where the cutting machine is initially mounted, perpendicular to the cutting blade(at an angle of 0°). The mounting can either be standard, where the left side of the rotary lever touches the cutting blade, or non-standard with an exact predetermined offset, to cut objects of lengths shorter than the offset length. [5]

A. Calibration of the measuring system:

To calibrate the device for maximum precision, access the calibration page on the HMI. There are 3 sets of arrows that enable the user to control the speed of the slider (Fig. 6). This allows the user to move the rotary lever in line with the cutting blade. Once the lever touches the blade, press the "set zero" calibration button. At this point, the measuring system places the motor encoder in the zero position (once the blade is touched by the end of the rotary lever). The next step is to enter the desired length using the keyboard of the HMI.

The desired length is input in the home screen, and the entered length will be displayed to confirm the movement of the lever to the appropriate length. Once the length is verified, the "GO" button is pressed and the motor moves the lever to the appropriate distance commanded. The measurement offset can also be added in the “calibration” page.

This offset can be a fixed value equal to 30 inches (762 mm), established by the manufacturer. If the 30 inch (762 mm) build offset is inserted, the rotary lever must be mounted in the 180° position. This constructive offset can be modified according to the preference of the user. The object used for the offset can also be cut with this measuring system because it is very precise, with a precision of 0.02 millimeters. There is virtually no limit to setting the length of this offset.

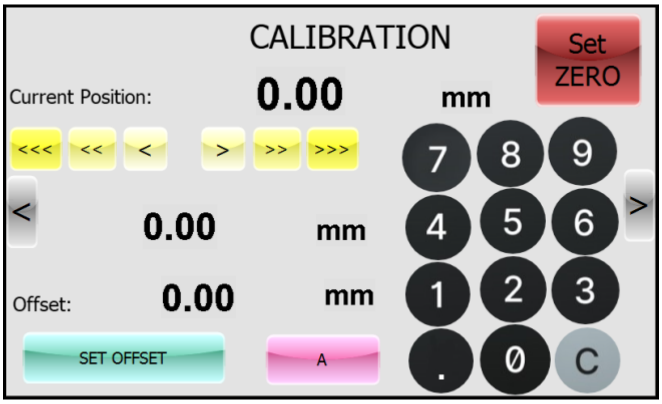

Fig. 6. GUI - Calibration page

The “options” page of the HMI can be used to adjust the speed and acceleration, as well as to choose the measurement units (metric or imperial).

V. OPTIONS FOR ENTERING LENGTH DATA

A. Metric system:

The user can choose between 2 options to enter a value. The first is of the format “xxxx.xx” where the user enters a number of upto 4 digits as an integer and two digits as decimal places using the keypad. The maximum value that can be entered is 9999.99 mm. The second is of the format “xxxx cm x mm .xx” where the last 2 digits are decimal places. The centimeter and millimeter keys are located above the keyboard as “F/C" and “I/M" respectively (Fig. 2), whereas the decimal key is a part of the numeric keypad. To add a value in this format, first input the centimeter value, for example, 123, and then press the “F/C” button, then the millimeter value, for example, 9, and press the “I/M” button, then write the decimal places, for example, 99, and press the “/” button. The final value according to the example will be 1239.99 mm. To accept and execute, press the “GO” button.

B. Imperial system:

The user has 2 formatting options to choose from, in the same way as the metric system. In the first format, the user can enter a number of 3 digits as a whole number and 3 digits as decimal places on the keypad(“xxx.xxx”). The maximum value can be 999.999 inches. The second is of the format “xx feet xxx inches x/x”. The keys for feet, inches and fraction are located above the keyboard as “F/C”, “I/M”, and “/”, respectively (Fig. 2). To add a value in this format, first input the feet value, for example 12 feet, and press the “F/C” button, then the inch value, for example 345 and press the “I/M” button, then write the fraction counter, for example 7 and press the third button. “/”, then write the denominator of the fraction, for example 8. The total value will be 12’ 345 ⅞” which is equal to 489.875 inches. To accept and execute, press the “GO” button.

C. Angular operation:

To calculate the lengths L1 or L4, which are shown in the figure below, the user must enter the desired cutting angle, along with one of the lengths L2 or L3. Depending on the situation, the user can choose between the modes displayed at the top of the calculation page, for a calculation corresponding to the desired cutting situation.

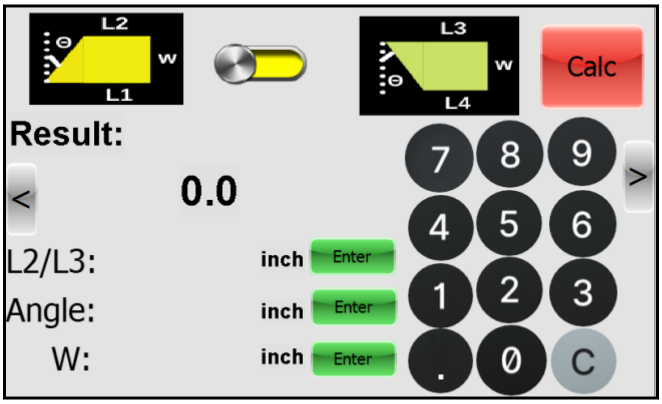

Fig. 7. GUI - Calculation page for angular operation

VI. CUSTOM CONSTRUCTION PARAMETERS

The measuring device is versatile and can easily meet the needs of each user. The custom parameters are read from a SD card while the setup page of the system on the screen (Fig. 8). Some users may need a smaller or larger measuring device, and this is accommodated by using an optional card that contains the construction parameters on a text file named “Config.txt”. As the needs of the user differ, each parameter changes. In the text file, the user can specify the construction parameters which they would like to update. The type of parameters are, STROKE (length of aluminum profile which slider is mounted on in mm), PPR(maximum encoder value of the SD motor) , MPR(displacement of the slider when motor make one full rotation in mm), OFFSET_A (length of the rotating plate offset in mm), MAX_VEL (maximum velocity in mm/s), and MAX_ACC (maximum acceleration in mm/s^2). The Config.txt file must be formatted to FAT32. Description of the parameter is all caps and separated with the value with colon. Users must mark the end of the Config.txt with a semicolon (Fig. 9).[6]

Fig. 8. Setup page

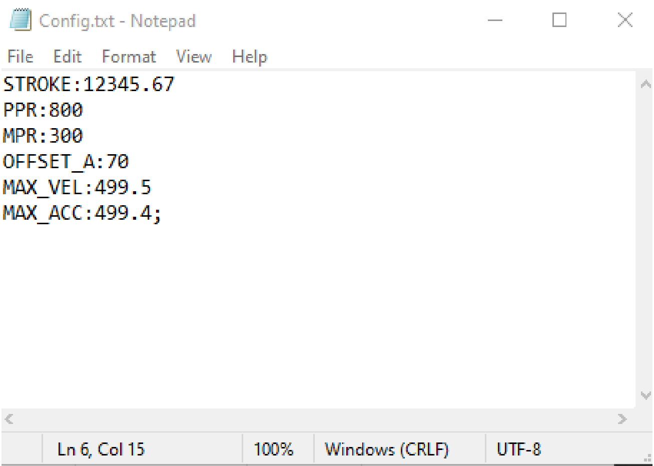

Fig. 9: Config.txt file

VII. MATH

The mathematical formula used to translate human units to the pulse increment/decrement command to the motor is as shown in equation (1):

$$Pulse = Input \cdot \frac{Pulse\ Per\ Rotation}{Pitch} \tag{1}$$

Here *Pulse* is a rounded integer value. *Input* is the input value entered by the user which is converted to millimeters. *Pulse Per Rotation* is the number of encoder steps for the motor. *Pitch* represents the pitch of the ball screw. All inputs from the user need to be converted to the equivalent pulse value, since the motor does not have a sense of distance. Instead, the motor keeps track of the encoder values.

The *Software Limit* is defined as in equation (2).

$$Software\ Limit = Physical\ Limit + Offset \tag{2}$$

The variable *Software Limit* is dependent on *Physical Limit* due to the length of the ball screw (mechanical structure) and *Offset* set by the user. *Offset* can be set to any value by the user in the “calibration” page. Therefore, the system is able to adapt to any mechanical setup.

The *Result* in the angle cutting option is calculated as shown in the equations (3).

$$Result = Length - \frac{Width}{\tan\left((90° - Angle)\cdot\frac{\pi}{180°}\right)}$$

$$Result = Length + \frac{Width}{\tan\left((90° - Angle)\cdot\frac{\pi}{180°}\right)} \tag{3}$$

The above equations can be used to find either the longer side of the piece or shorter side of the piece respectively, given by *Result*. *Length* represents the length of the cutting stock opposite to the length that the user desires to calculate(*Result)*. For example, if the user wants to calculate the length L1, then *Length* in this case is equal to L2 (Fig. 7). *Width* is the width of the cutting stock. *Angle* is the angle between the blade and cutting surface of the stock.

When the user controls the slider using the 3 arrow buttons(also known as jog buttons), it has to be ensured that the slider does not immediately stop, which may cause significant damage to the mechanical structure. Hence, a formula has been deployed that decelerates the slider as soon as the user stops using the jog buttons, while ensuring protection to the mechanical structure of the system. Real time position of the slider is kept tracking whenever the motor is in motion (4):

$$Real\ time\ velocity = \frac{(Current\ slider\ position(mm) - Previous\ slider\ position(mm))\cdot 1000}{Current\ time(ms) - Previous\ time(ms)} \tag{4}$$

Using (5), the motor decelerates to stop approximately 0.5 second from the user stop pressing the jog button.

$$Deceleration = \frac{Real\ time\ velocity}{0.5} \tag{5}$$

VIII. CONCLUSION

The proposed measuring system is highly valuable in conditions where a precise measuring system is required. The software offers many input options, yet it is intuitive for new users. A high contrast display is designed for both exterior (bright ambient) and interior (dark ambient) environments, and updates users with relevant information during the operation. Lastly, the internal encoder value is monitored to ensure precise movement of the stopper.

Conflict of Interest

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Jin De Guillaume was involved in the development of the software, and the composition of the paper.

Karthick Sivasubramanian was involved in the development of the software, and the composition of the paper.

Niculae Mihai coordinated the teams, wrote the initial draft of the papers and developed the mechanical structure of the system.

Hadi Faour was involved in designing the mechanical structure of the system.

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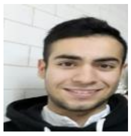

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