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DEVELOPMENT AND EVALUATION OF A CHOPPING MACHINE FOR FORAGE CROPS

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ABSTRACT

Silage is an important bulk feed source and is an indispensable part of rations in animal feeding due to its high nutritional value, ease of use, and ability to provide feed during the off-season. Generally, silage materials chopped by silage machines in the field are transported to the silage storage area by carrying vehicles. After being unloaded into the silo, they are subjected to compaction using compaction equipment. One of the important issues that researchers have been working on is the effect of the relationship between the silage density obtained after compaction and the particle size of the silage materials on silage quality. This study describes the implementation of a monitoring and control system based on Programmable Logic Controller (PLC) technology for chopping silage materials into different sizes in a laboratory environment.

Two cutting blades have been mounted on the rotor of the designed chopper. The developed chopper has two geared electric motors: the first drives the feeding rollers, and the second drives the chopping rotor. Drivers controlled by a PLC operate these motors. The machine is equipped with belt-pulley mechanisms as transmission elements. The chopper has been designed with a flexible structure to operate at different speeds using various pulley ratios when needed.

In the experimental studies, the machine's cutting performance for silage corn stalks was evaluated as particle sizes 2, 4, and 6 cm. The test results demonstrated that the machine successfully performed the cutting process at the sizes entered through its control unit. Additionally, preliminary trials showed that the machine could also cut wet/dry hay, stalks, alfalfa, and tree branches with a diameter of 16 mm.

1. INTRODUCTION

Animal nutrition is one of the most serious problems faced by animal producers and this problem can be solved by selecting the appropriate animal diet at the right stage [1]. Physical treatments of poor-quality roughage before chemical processing enhance the material's acceptance for chemical improvements. Examples of physical treatment include chopping, shredding, grinding, and pelleting. Grinding and pelleting fibrous materials increase the surface area exposed to microbial attack and speed up digestion as materials move through the gastrointestinal tract [2]. Chopping fodder and straw into smaller pieces before feeding them to animals increases digestibility, improves palatability, and conserves energy used during mastication. Fodder-cutting techniques can be performed manually, with a diesel-powered machine, or using an electric-powered machine [3].

Silage maize, often referred to as the "king of feed," is characterized by its high content of crude protein, sugars, carotene, and other vital nutrients, making it an essential feed source for dairy and meat production globally [4,5,6].

Researchers have shown significant interest in the effects of particle size on silage quality during the preparation process. This has intensified the need to determine the suitability of newly developed forage crops for silage application. Therefore, there is a need for silage preparation systems, particularly chopper machines that researchers can use quickly in laboratories without being dependent on field conditions.

Randbu et al. [7] investigated the effects of chopped particle size and concentrated protein levels on feed consumption and milk production in dairy cows using harvested grass silage.

Saute et al. [8] investigated the effects of silage density and particle size on silage quality using Paiaguás grass in PVC silos. The study employed silage materials with compaction densities of 550, 600, and 650 kg/m³ and particle sizes of 5, 8, and 12 mm.

As the diversity of silage plant species increases, the demand for chopper machines in laboratory studies remains relevant and significant.

Ghobashy et al. [9] developed and assessed a duel-purpose machine for chopping operations using maize stalks with four different rotational speeds of 1200, 1400, 1600, and 1800 rpm and four different moisture contents of

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22.7, 43.3, 59.8, and 74.6% (w.b.). Also, they evaluated the crushing operation using maize ears with four different crusher speeds of 1200, 1400, 1600, and 1800 rpm and three different sieves with holes' diameters of 6, 8, and 10 mm.

Chen et. al. [6] optimized the design and experiment on a silage maize harvester's feeding and chopping device. Horizontal feeding devices and plate hob chopping devices are the key components of silage maize harvester. To solve the problem of feeding blockage and reduce energy consumption, they designed a horizontal different-diameter five-roller device (HDDFD) and optimized the plate hob chopping device simultaneously. Through the dynamic analysis, the feeding conveying speed was determined to be 2.0-4.5 m/s.

Nipa et al. [10] designed and developed a small-scale fodder-chopping machine, and its performance was tested. This machine provides flexibility to use two blades to cut different lengths of fodder.

Hegazy et al. [11] modified a star forage chopper machine (SFCM) to reduce energy consumption and improve forage-cutting efficiency. The SFCM's performance was assessed based on cutting rice straw, and cotton stalks at varying feed rates and knife speeds. The minimum cut length for rice straw was 13.5 and 12.7 mm for cotton stalks.

Okasha [12] modified a local thresher machine to mince and chop agricultural leftovers, such as rice straw and corn, while minimizing energy consumption. The modified machine utilized two different types of blades (free sharp blades + serrated discs). Its performance was evaluated based on productivity and cutting efficiency for two distinct crops of corn stalk and rice straw under three operating speeds of 1200, 1600, and 2000 rpm at three moisture contents of 8, 10, and 12%.

Khairy et al. [13] developed a straw-chopping machine considering the physical properties of rice straw. Their analysis concluded that the maximum productivity reached 6.03 $kg \cdot h^{-1}$, while the optimal specific energy requirement was 52.08 kWh at a drum speed of 1,600 rpm.

Aboamera et al. [14] evaluated the performance of a modified local maize-chopping machine, focusing on changing machine rotational speed, moisture content of corn, and feeding quantity. As a result of their studies, they identified the highest chopping time, the highest fuel consumption rate, maximum cutting efficiency, and the highest machine productivity. The highest rate of fuel consumption was 3.65 lit/h. kg. was observed at 73.45% of corn moisture content with 1.56 kg of feeding quantity. Maximum efficiency (96.96%) occurred at 54.11% of corn moisture content at 0.67 kg of feeding quantity.

Ghaly et al. [15] constructed a straw chopping system designed to provide a continuous flow of straw to a fluidized bed gasifier, evaluating its performance characteristics, including rotational speed, feed rate, depth of cut, length of cut, and energy required for chopping. It was concluded that decreasing the cutting depth and/or increasing the cutting speed increased the straw feeding rate while increasing the cutting depth and/or increasing the cutting speed increased power consumption and decreased the straw length.

The literature review indicates that researchers concentrate on both the design and development of more efficient chopping machines and enhancing the operational performance of the chopping machines already in use. The purpose of the laboratory-type chopping machine developed in this project is not to achieve a high cutting capacity in a short time, but to safely cut the material provided according to the dimensions specified by the researcher. The developed chopping machine is a PLC-controlled device that does not have comparable examples in the literature review. It can cut silage material to the desired length based on values entered through the operator panel.

2. MATERIAL AND METHOD

As part of the project, a PLC-controlled chopping machine was designed and manufactured to chop silage materials to specific sizes in a laboratory environment (Figure 1a). The designed rotor incorporates two cutting blades. The unit is equipped with belt-pulley mechanisms that allow it to operate at 60, 120, and 180 rpm. Additionally, the machine can be adjusted to operate at different speeds by changing the pulley ratios. The machine is capable of chopping wet/dry hay, stalks, alfalfa, maize stalks, cobs, and tree branches up to 10 mm in diameter. The cutting blades used in the unit were produced from 1.2379-grade steel with a hardness of 44 HRC (Figure 1b). The specifications of the cutting blades are listed in Table 1.

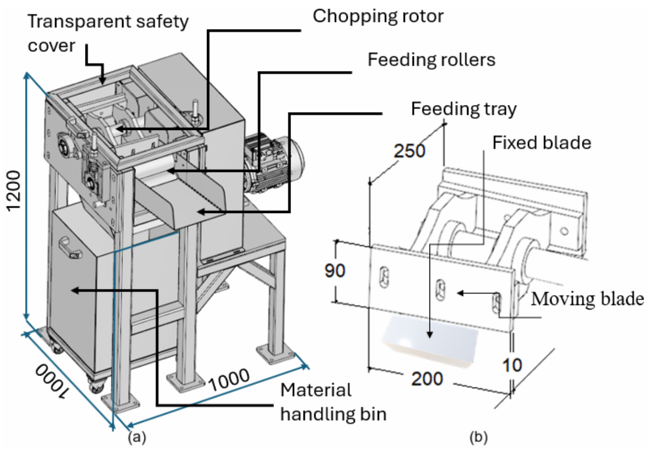

Fig. 1. a) General view of the machine, b) Chopping blades

Table 1 *Chemical Composition of Cutting Blades Made from 1.2379 Material*

C	*Cr*	*Mo*	*V*
1.55	*12.0*	*0.70*	*1.00*

Control Unit

The system controlled by the PLC featured a relatively simple electromechanical setup, which minimizes cost and maintenance. An industrial PLC was used to control the speed of AC motors via two Micno Speed Controllers. In Figure 2, the overall system design is illustrated.

The system consists of hardware and software units. A PC runs Window-based software programs known as GMTSoft and ENDA.EOP. The GMTSoft was used to develop and verify the control program for the PLC, while the ENDA.EOP was utilized for designing graphical screens for the Human Machine Interface (HMI). The ladder diagram method has been used to write the control program for the PLC (Fig. 3). The control program was downloaded to the PLC via an Ethernet communication cable, while the HMI program was transferred to the HMI using a USB cable.

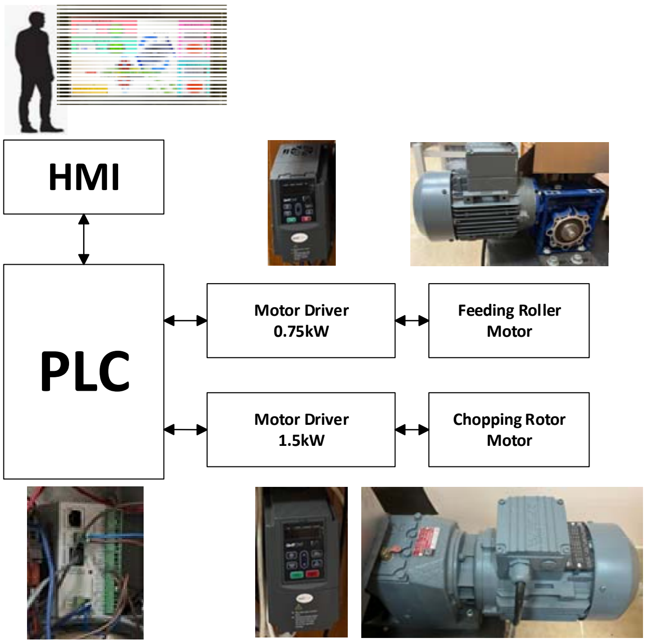

Fig. 2. Overall System Design

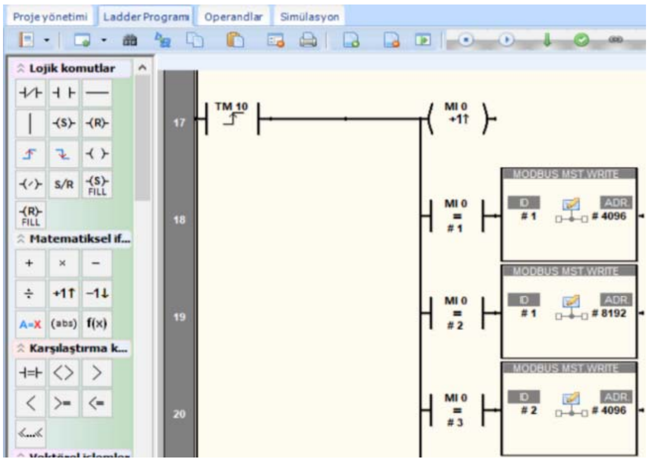

Fig. 3. Part of the PLC program

Enda PLC GLC 386RT CPU module was used as a control unit. The PLC control unit supports 4 relay outputs, 2 pulse outputs (12,5kHz), 1 analogue input (0-10VDC, 10 bit resolution) and 1 analogue output(0-10VDC, 14 bit resolution), 1 port RS232, 1 port RS485, 1 port Ethernet, RTC (real-time clock).

Table 2 *Technical Features of Inverters*

Supply voltage	*Micno-00150H: 3x380VAC (Three phase)*	*Micno-00075S: 1x220VAC (Mono phase)*
Power	*Micno-00150H:1.5kW*	*Micno-00075S: 0.75kW*
Communication	*RS-485 communication supporting standard MODBUS RTU protocol*	
Digital Input	*6 PNP or NPN digital inputs*	*5 PNP or NPN digital inputs*
Analog Input/ Output	*1 programmable 4-20 mA or 0-10 V selectable analog output*	

This PLC system features a modular design consisting of specific hardware expansion modules that connect directly to one another: a central processing unit (CPU), analog/digital input/output modules, temperature module. Modular approach has the advantage that the initial configuration can be expanded for other future applications.

GMTCNT Micno-00075S and Micno-00150H have been employed as the ac motor drivers (Table 2). These inverters serve as interfaces between the PLC and the motors. The inverters have been configured to receive signals from the PLC. This was done using the inverter's programming terminals. The PLC sends the necessary control signals to the inverter to adjust the desired speed and torque of the motor. These signals are typically in the form of analog voltage signals (for example, 0-10VDC).

The motor specifications are given in Table 3 and Table 4.

Table 3 *Feeder motor parameters*

Motor Type	*3EL080M4D*
Output Power	*0,75kW*
Speed	*1500 rpm*
Frequency	*50Hz*
Voltage	*230/400 V (D/Y)*
Torque	*4.94 Nm*
Moment of Inertia	*0.00227 kg.m²*
Efficiency	*82.5% for load 4/4 (IE3)*
Power Factor	*0.74*

Table 4 *Chopper motor parameters*

Motor Type	*MR103-2E80M/4C*
Output Power	*0,75kW*
Speed	*1440 rpm*
Frequency	*50Hz*
Voltage	*230/400 V (D/Y)*
Torque	*4.97 Nm*
Moment of Inertia	*0,00220 kg.m²*
Efficiency	*79.6% for load 4/4(IE2)*
Power Factor	*0.72*

A Human Machine Interface (HMI) has been used for the user to interact with the system. In this study, the Enda Industrial Electronics EOP41-070ETE HMI is used to input the speed values of the motors. The user can also turn ON or OFF the system through the touch buttons placed on the HMI screen (Figure 4). An emergency stop push button has been located on the control cabinet for easy access by the user. HMI was connected to PLC by an RS232 cable.

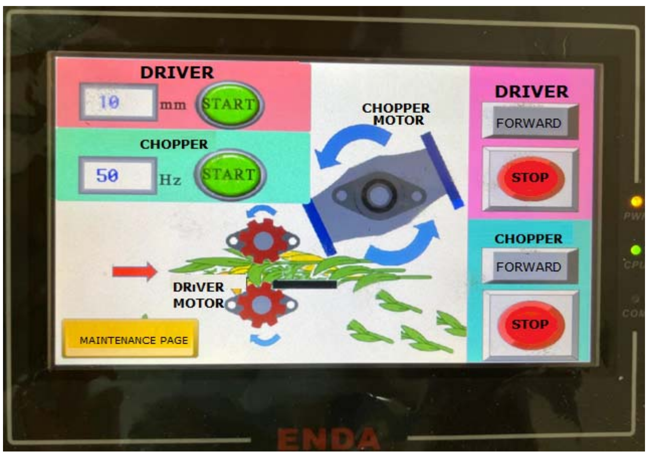

Fig. 4. HMI Screenshot of the developed system

Through the HMI interface, the system's start-stop operations and particle size adjustments can be controlled. The particle size adjustment is performed by directly inputting the desired size in the drive section. Based on the entered value, the system automatically adjusts the speed of the feeding rollers, allowing the material to be chopped to the specified size. The chopper rotor is typically operated at its maximum speed of 50 Hz. If larger particle sizes are desired, the rotor speed can be reduced to achieve the required particle dimensions.

3. RESULT AND DISCUSSION

The chopped materials were subjected to a size analysis. The material was sieved, and a scale was used to measure larger pieces that remained on the sieve, followed by manual size analysis. The research results regarding the chopping unit are presented in Table 5, and Figure 4 illustrates the distribution of particle sizes at different chopping rotor and feeding roller speeds. The chopped material was classified into six different size groups. At the highest blade speed and the lowest feeding speed, the system achieved 75% chopping efficiency with particle sizes of 10 mm. Figure 5 shows the machine in operation in the laboratory.

Fig 5. Operation of the machine in a laboratory setting

Table 5 provides the average chopping sizes obtained at three different blade speeds. The increase in the blade's peripheral speed resulted in a decrease in the average size of the chopped material. Therefore, it is possible to obtain the desired chopping sizes by entering the values into the chopping unit via the HMI panel. Naturally, the chopping sizes are influenced by various parameters such as feed rate and moisture content of the material. Further trials are needed to assess the effectiveness of the chopping unit under different conditions. Figure 6 shows the particle size distribution at different blade speeds.

Table 5 *Average Chopping Size for Different Rotor and Roller Speeds*

	Particle sizes (cm)	*Chopping rotor (rpm)*	*Chopping rotor frequency (Hz)*	*Feeding rollers (rpm)*
1	*1*	*180*	*50*	*15*
2	*2*	*180*	*50*	*30*
3	*4*	*150*	*40*	*50*
4	*6*	*100*	*30*	*50*

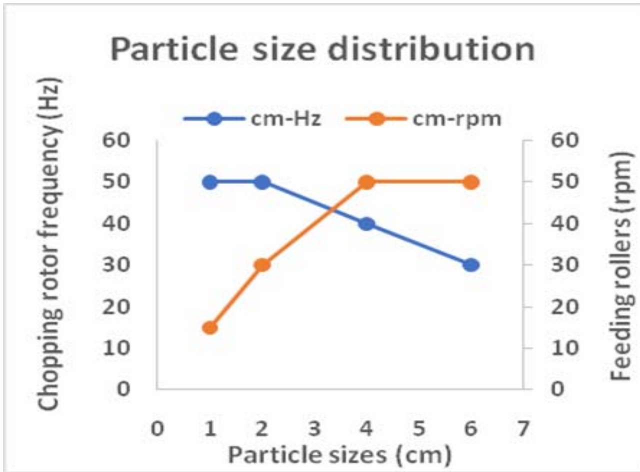

Fig 6. Particle Size Distribution at Different Blade Speeds

4. CONCLUSION EXPOSITION

The chopping unit developed in this study is capable of processing materials of varying maturity and dry matter content, offering the ability to cut at different feed rates and particle sizes as required. For safety reasons, the machine's speed was kept low during the experiments. However, it was observed that at lower speeds, the machine sometimes struggled to chop maize stalks. Therefore, increasing the speed would enhance cutting efficiency and allow for more work to be done in less time. Further studies should focus on optimizing the chopping speed for maximum efficiency.

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