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Development of a Semi-Automatic Machine for Manufacturing Low-Cost Concrete Blocks for the Civil Construction Industry

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***Keywords*— Semi-automatic block making machine, Civil construction Industry, Hydraulic system, Machine design, Low cost project.**

***Abstract*— *This work addresses the development of a low-cost semi-automatic machine for manufacturing concrete blocks, aiming to meet the growing demand in the civil construction industry for equipment that offers greater productivity and economic viability for small and medium-sized entrepreneurs. Based on studies and market analysis, the design and selection of materials and components were carried out to minimize failures related to abrasiveness and dynamic loads. The project consists of a simplified manual-hydraulic system, incorporating constructive solutions typical of high-performance automatic models, with appreciable robustness and wear resistance. The results obtained prove the technical and economic viability of the equipment which has significantly lower cost than automated hydraulic models available on the market. It is concluded, therefore, that the project fully meets the objective of reconciling low cost with durability and high productivity, establishing itself as a competitive and innovative alternative in the civil construction market.*

I. INTRODUCTION

The manufacturing of concrete blocks plays a fundamental role in the civil construction industry, with its use becoming popular due to its durability, strength, and ease of assembly, [1]. This billion-dollar market demands large-scale production with quality, which requires the use of appropriate machines for manufacturing the blocks, aiming to guarantee quality and reduction of costs.

There are several machine options on the market, from manual models to fully automatic equipment. However, it is important to consider that high-productivity and robust machines generally have a high cost, which can be challenging for medium or small companies. On the other hand, lower-cost machines do not always offer the same performance or robustness, compromising the efficiency and quality of the blocks.

In this context, it is necessary to develop a concrete block manufacturing machine that combines high productivity, robustness, and affordable cost. This combination would allow manufacturers to reduce production costs, increase competitiveness, and offer better quality products.

Based on the above, the need to develop machines that combine low acquisition cost with productive efficiency and product quality was observed. In this sense, it is highlighted the need for constant updating of the productive and managerial processes of civil construction, [2]. The use of semi-automatic machines can be a viable alternative, balancing the simplicity of manual processes with the advantages of partial automation, mitigating the problems of fully manual machines and contributing to greater productivity.

Thus, the present work presents the developing a semi-automatic concrete block manufacturing machine, with low cost and intended to meet the demands of civil construction, optimizing production processes and reducing operating costs, promoting greater economic viability for small and medium-sized producers.

The manufacturing of concrete blocks is a complex process that involves steps such as mixing materials, compaction, curing and demolding. Each of these steps requires specific equipment and trained labor. The introduction of an efficient and low-cost concrete block manufacturing machine could optimize this process, providing greater speed, precision and standardization in production.

One of the main benefits of a highly productive and robust semi-automatic machine at an affordable cost is the reduction in production costs. With an efficient machine, it is possible to increase production, reducing cycle time and minimizing material waste. In addition, the standardization provided by the machine ensures uniformity and quality of the blocks, which can result in resource savings by avoiding rework and reducing the number of blocks discarded due to defects.

The pursuit of high productivity in concrete block machines leads to the use of hydraulic actuators. Hydraulic actuators not only allow for high productivity but also improve the finish and standardization of the concrete blocks produced, [3]. Furthermore, to achieve the desired performance, it is necessary to seek new solutions in components that combine high strength and ease of manufacturing.

From an environmental point of view, well-developed projects can favor the reduction of material waste and the optimization of energy consumption. These are aspects to be considered by companies in the civil construction industry that optimize their processes and demonstrate the possibility of obtaining profit with actions that benefit the environment, [4,5].

II. MAIN TECHNICAL CHARACTERISTICS

Hydraulic System and Actuator

In the design of the semi-automatic machine, a drive system is defined to guarantee the supply of uniform force and movement necessary for compaction and demolding. The hydraulic system chosen is shown in Figure 1, which is justified by its technical superiority in relation to the requirements of higher workloads and its greater resistance to the adverse environmental conditions common to this type of machine.

Fig.1. Hydraulic unit with valve block and levers.

The machine's primary function is to generate high force for pressing the concrete in the mold, ensuring the block's strength and low porosity. The power density of the hydraulic system offers significantly more power than the pneumatic system. The block production environment, loaded with fine cement dust and abrasive aggregates, is hostile to open-circuit systems. Adopting the hydraulic system significantly mitigates the environmental impact and maintenance costs.

In a closed circuit and with its seals, the hydraulic system operates with the oil sealed and recirculated within a reservoir. Furthermore, the connecting elements are designed to be hermetically sealed to prevent leaks due to high pressures. These seals protect internal components, such as valves, pumps, and cylinders, from external contamination by cement dust and sand, ensuring a longer and more predictable service life.

The machine design is fundamentally semi-automatic, which implies a simplified and manual control architecture. In systems like this, automation does not replace the human being, but transforms them into a supervisor and operator of the process. This approach, where the machine performs the heavy work and the operator dictates the sequence, is strategic to ensure maximum simplification of the system, aligned with the premise of low cost and greater safety for the operator.

The management of the machine's movements is centralized in a mobile type hydraulic valve block, actuated directly by mechanical levers. This type of valve block is the same used in trucks, tractors and heavy machinery, giving great robustness to the control system of the machine's actuators.

The hydraulic unit provides hydraulic energy through an industrial pump with a maximum working pressure of

120 bar and a fixed flow rate of 10.5 l/min, which is limited by the rotation of 1750 RPM of the 7.5 HP motor. The hydraulic unit incorporates a structure where the valve block is fixed. The valve block incorporates a pressure gauge and a pressure regulating valve, with the working pressure set at 40 bar to avoid overloading.

The levers are mechanically connected to the directional valves, which control the flow of pressurized oil to the actuators through hoses, which in turn exert the force necessary to perform the machine's functions. The operator is responsible for observing the movements during the execution of each machine function and for activating the levers to perform the forward and return movements of each actuator. The valve block with its respective levers, fixed to the hydraulic unit, provides better positioning for the control area, improving the operator's observation position and optimizing their sensory function.

The hydraulic power unit has the electric motor of the hydraulic pump, which is activated by a switch and contactor, being the only electrical control element responsible for supplying pressure to the hydraulic system. Since safety is a crucial factor, an emergency stop button, mushroom-type with a lock, was incorporated into the electrical control panel design, Figure 2. This button interrupts the power supply to the hydraulic pump motor and the motors that drive the vibrators, ensuring the safe shutdown of the system in any imminent risk situation, in accordance with regulatory standard NR 12.

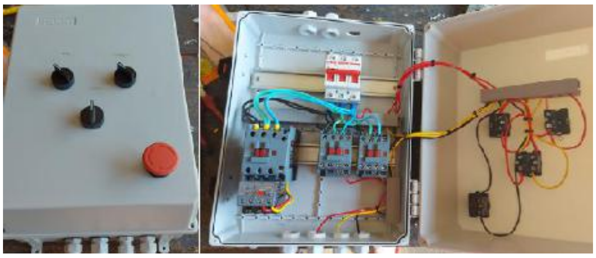

Fig.2. Electrical panel with emergency stop button.

The production sequence is conducted by the operator, who uses the levers in a predetermined order, according to the operational checklist sequence:

A) Feeding - The operator activates the feed drawer lever, observing the mold filling, and returns the drawer;

B) Compaction (Pressing and Vibration) - The operator activates the pressing cylinder lever, keeping it activated until the press penetrates the mold about 15 mm. (The noise at the end of pressing is more noticeable to the operator than the perception of the press sinking);

C) Demolding - At the end of pressing, the operator activates the lever to raise the table with the mold, and when the entire table is raised, activates the lever raising the ejector;

D) Removal - After demolding, the operator activates the lever to insert a new board, ejecting the board with the newly demolded block;

E) Repetition - The operator returns the table to the initial position (via lever) and starts a new cycle.

In this architecture, the operator's ability to observe and pay attention are the limiting factors for repeatability and cycle speed. However, the gains in terms of construction simplicity and the drastically reduced cost justify the reliance on human intervention for operation.

Structural Aspects and Main Mechanisms

The main factor in structural degradation in a concrete block machine is precisely the dynamic loads to which the equipment is subjected. For this reason, understanding the severe dynamic loads that must be considered for the appropriate dimensioning of the structure and other components is fundamental to the quality and resistance of the machine.

The compaction of the concrete in the mold occurs through vibrators, whose power transmission is done from the motors to the vibrators through belts. The vibrators generate high-frequency oscillatory forces on the table where the mold is fixed, which consequently end up being transferred to the machine's structure. This vibration, which is a function of the weight of the eccentric masses and the rotation frequency of the motor, is transmitted integrally to the mold and partly to the chassis or structure of the machine.

The impact of this load is critical, since fatigue, along with corrosion and wear, are the main causes of failures in metallic structures. Structures subjected to cyclic loads, such as block-making machines, undergo a continuous deterioration process that manifests itself through the appearance and propagation of cracks. Inadequate dimensioning can lead to structural cracks long before the expected service life of the machine.

Another impact that negatively affects the machine's operation is the loosening of bolts and the destabilization of connections, which are direct consequences of intense vibration. This can compromise the entire process, generating losses, unexpected stoppages, misalignments, directly affecting the productivity and quality of the blocks produced, [6].

For this reason, bolts, nuts, and studs used in critical joints, especially in the fixing of vibrators and in the couplings of the vibrating table to the guide, were specified with the use of mechanical locking, with self-locking nuts or locknuts and, in some cases, chemical locking, ensuring that the connections remain rigid and aligned during the operating cycle.

The intense vibration generated by the vibrators, Figure 3, although essential for the quality of the block, is highly destructive to the machine and its components. The table, being the machine component where the vibrators are fixed, must transfer the maximum vibration to the mold, leading to the compaction of the concrete. Since the table is a movable piece fixed to a guide, this junction is a critical point, as it must guarantee good rigidity for the mold to move precisely, but must not allow the vibration to be conducted to the machine structure. For this reason, the design was based on the use of passive damping elements, Figure 4. Elastomeric rubber cushions, through the optimization of their rigidity and damping characteristics, were successfully employed.

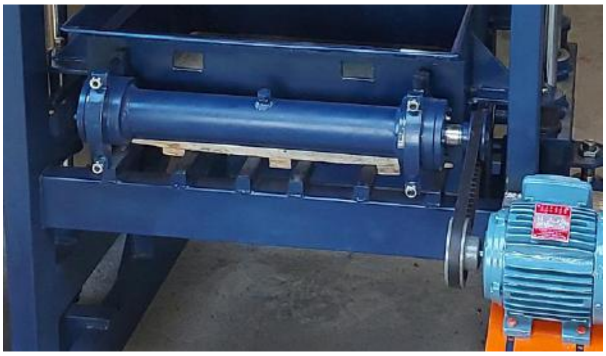

Fig.3. Vibrator assembly, belt and motor.

The most thermally and dynamically stressed component of the machine is the vibrator. Prioritizing robustness, the vibrator was built from an eccentric shaft, supported by 32307 tapered roller bearings, commonly used in the front axles of trucks and heavy vehicles, immersed in a sump filled with automotive lubricating oil. The sump is a 3-inch steel tube with two reinforced rings on the sides to receive the bearings, a blind cap on one side and another with a hole and retainer for the passage of the eccentric shaft end, where the pulley is attached that will be driven by the 2 HP electric motor via a belt.

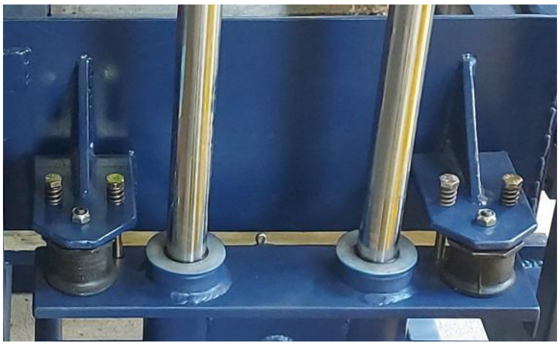

Fig.4. Detail of the use of cushions with screws and springs that limits tension.

The choice by this vibrator offered three significant advantages: the inherent robustness of the tapered roller bearings, which are designed to withstand significantly higher axial and radial loads than common ball bearings, effectively absorbing the intense forces of the vibrator; reduced maintenance, guaranteed by oil bath lubrication, which better dissipates the heat generated by high rotation, providing a longer service life than grease and reducing the frequency of interventions; and excellent cost-effectiveness, since the use of standardized automotive bearings ensures high component availability at a substantially lower cost than that of an industrial vibratory assembly.

Fig.5: Pendulum mechanism of the drawer.

The drawer, in turn, has a stroke of 750 mm. Using a hydraulic actuator to cover this entire stroke would result in a high cost, contradicting the premise of the low-cost design. In addition, it would lead to a considerably long cycle time and imply a shorter service life for the seals and bushing in the head, due to its elongated stroke in the horizontal position and the high perpendicular loads added to the vibration. As an engineering solution, the project adopted the strategy of performing the drawer movement secondarily, through a pendulum mechanism attached to a shaft, as shown in Figure 5. A hydraulic actuator with a stroke of 290 mm – less than half the total stroke – exerts the movement on a force arm coupled to this shaft. The angular movement generated by the actuator is transferred to the drawer by a lever arm with a larger radius. In this way, the drawer moves its 750 mm stroke with the reduced-stroke actuator, which more than doubles the speed of drawer movement and ensures a more compact and robust component.

Abrasiveness Mitigation

Although the mold and ejector are considered periodic replacement elements, with the cost diluted in the total production, the primary focus of the project falls on the structural moving components that, if worn, compromise the machine's operation.

The sliding guides that ensure the movement of the vibrating table and the press are the most critical points of the machine with regard to abrasion wear. Vibration tends to disperse fine particles of cement and aggregates out of the mold, and these particles infiltrate the gaps between the bushings and the structural guides. In these gaps, the dust acts as a powerful abrasive agent, accelerating the wear of the guiding surfaces and compromising the parallelism and alignment of pressing and demolding, increasing the probability of failure or interferences.

With technological advances, engineers and researchers are increasingly required to learn and master other materials, an example being the polymer that currently replaces some metals. And, in response to the challenge of the infiltration of fine abrasives into the sliding guides, the project sought the use of engineering polymers, which offer a low coefficient of friction and high chemical and abrasive resistance.

The choice of engineering polymers, such as nylon, for the manufacturing of the bushings and rollers for the drawer is justified by their exceptional hardness and resistance to wear. This characteristic is valuable in mechanical components subject to continuous friction and, especially, in environments with abrasive particles, guaranteeing impressive longevity for items such as bushings and pulleys, even in challenging conditions, [7].

A detail added to the nylon bushings, which ensured greater longevity for the assembly, was the incorporation of scraper rings, as can be seen in Figure 6(a), by machining a recess on the inside of the bushing. These components are off-the-shelf items and are usually made of polyurethane, and have a low acquisition cost. They provide great protection to the system, as they prevent abrasive particles from infiltrating the inside of the bushing.

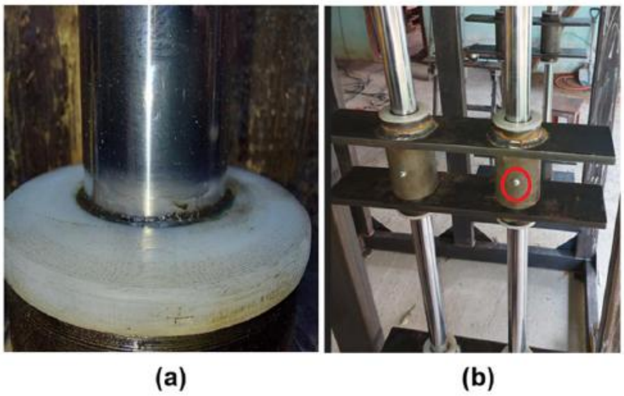

Fig.6. (a) Detail of the bushing with the built-in scraper; (b) Parallel guides and bushings with grease nipple system.

For the guides, the project sought materials with wear-resistant characteristics found in high-performance coatings. Industrial hard chrome layers, for example, demonstrate superior hardness to quartz (between 800 and 1,200 Vickers) and have a stable oxide film on their surface, which guarantees repellency, a low coefficient of friction, resistance to micro-welding, and hardness. These characteristics were found in solid 1045 carbon steel bars, with an industrial hard chrome surface treatment, the same used in the hydraulic actuator rods.

To ensure precision and better alignment in the movement between the mold and the press, parallel guides and a steel assembly were used to support the nylon bushings. A grease nipple was inserted into the assembly, as detailed by the red circle in Figure 6(b), in order to allow periodic lubrication of the seat, assisting in sealing and ensuring the fluidity of the movement, complementing the protection already offered by the built-in scraper.

III. COST ANALYSIS

The cost analysis of the project is a good quantitative proof that the engineering solutions resulted in a highly competitive product. The costs for manufacturing the prototype were listed and are presented in Table 1.

The total manufacturing cost is the sum of the direct costs of materials, commercial components, and manufacturing costs. Applying a 50% markup on the manufacturing cost yields a reasonable selling price.

Through a comparative analysis of the average market prices for machines with similar characteristics, a high level of competitiveness can be observed for the machine developed in this work, which can perform production cycles of approximately 30 seconds, with each cycle producing 4 to 12 blocks, depending on the size.

Table 1. Costs for manufacturing and acquisition of the items of the developed machine (rounded values).

Materials	
Steel profiles, sheets and bars	USD 2,379.63
Vibrators	USD 740.74
Chrome guides	USD 185.19
Bushing holder	USD 185.19
Nylon Bushings	USD 185.19
Actuators	USD 1,407.41
Subtotal 1	(USD 5,083.33)
Commercial Components	
Hydraulic parts	USD 527.78
Hoses	USD 490.74
Screws, nuts, washers	USD 168.52
Bearings	USD 240.74
Belts	USD 12.96
Cushions	USD 32.41
Nylon rollers	USD 61.11
Springs	USD 13.89
Motors	USD 820.37
Electrical components	USD 214.81
Inductive sensors	USD 46.30
Subtotal 2	(USD 2,629.63)
Manufacturing Costs	
Labor	USD 1,481.48
Inputs	USD 157.41
Subtotal 3	(USD 1,638.89)
Total Manufacturing Cost	USD 9,351.85

IV. RESULTS

The success of the project is validated by the evidence that the implemented engineering solutions ensured robustness and operational simplification, meeting the requirements for industrial performance and low maintenance costs. Figure 7 shows a general photo of a prototype of the semi-automatic block-making machine developed in this work. Figure 8 shows in detail the pressing process for manufacturing the blocks. Figure 9 shows examples of blocks produced.

Figure 7. Prototype of the block machine.

Figure 8. Pressing process for manufacturing the blocks.

Fig.9. Blocks produced.

The structural robustness of the machine was proven by mitigating the two main threats to the equipment's longevity: dynamic loads and the severe abrasiveness of the environment. The structural design was reinforced by adopting profiles with a larger cross-sectional area, in addition to inserting triangulations in critical joints to combat fatigue in welded joints. Vibration was contained by using standardized automotive elastomeric cushions, a solution that isolates vibration from the main structure with low cost and high reliability. As for the vibrator component, which is the most mechanically stressed, durability was increased by adopting oil-bath tapered roller bearings, which support heavy combined loads and offer a longer service life than grease lubrication.

Additionally, the longevity of the moving elements was ensured by abrasion resistance, where the guides use nylon bushings with built-in scrapers in conjunction with hard chrome-plated bars, a combination that provides low friction, protection, and repellency of fine contaminants, extending the time between maintenance. This combination of polymer bushings and chrome-plated guides is only found in high-performance automatic machine models.

Operational simplification and low failure risk were defined by the semi-automatic control architecture, where the system uses a centralized manual-hydraulic control in a MOBILE type valve block, eliminating the need for complex electronic components such as PLCs, sensors and I/O modules. This approach transfers the responsibility for the sequence of movements to the operator, ensuring constructive simplicity and eliminating specialized maintenance costs. The only electrical automation is the use of inductive sensors to drive the vibrators, leaving the operator freer to perform other operations, without having to also control the vibration time, one of the most critical parameters for the quality of the block, thus allowing vibration control to be applied consistently and stably.

V. CONCLUSIONS

This work demonstrated that the development of a low-cost, industrially robust semi-automatic machine is entirely feasible. The project achieved its overall objective by creating equipment that not only offers an affordable price for small and medium-sized entrepreneurs, but also incorporates durability solutions found in high-cost machines. The machine developed in this work fills the market gap offering a significant quality leap in concrete block production with a significantly lower initial investment, validating optimization engineering as a crucial factor for competitiveness.

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