Conceptual Design of a Lightweight Machine with Variable Control for Texturing on Concrete Surfaces

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***Abstract*— In Peru, constructions are commonly built with cement and bricks, then proceed to decorate and embellish the walls using texturing. Currently, in Peru, this process is done in a traditional way where generally support tools are used such as trowels, rollers, and brushes, among others. As this process is done manually, the texturing is of lower aesthetic quality. Due to its geographic location, Peru is one of the countries that most often applies cement in its constructions, which makes it the most accessible and suitable material for applying textures to walls. Currently, there is no specific machine for texturing, so the conceptual design of a lightweight machine for texturing on concrete surfaces was proposed using the VDI 2221 design methodology, integrating a variable speed control system and display of parameters in real-time.**

***Index Terms*— design, lightweight machine, variable control, texturing, slider-crank mechanism**

I. INTRODUCTION

Peru is a country where the building structure is mostly built under confined masonry techniques using cement, bricks, and construction materials [1], coupled with direct labor. According to an analysis made of the workers of the construction company Cristóbal Daza S.A.S., the repetitive movements of hands or arms in the construction sector represent 91% of ergonomic risk [2].

In our environment, after finishing the construction, people opt to apply texturing to interiors and exteriors spaces of their homes to decorate and beautify them. Most people choose to use materials such as ceramic, stone, and wood, among others, which gives their buildings a better appearance, but also substantially increases the total budget of the work [3]. These types of texturing can also be replicated using cement, although much depends on the skill of the operator.

Peru ranks 35th in cement production per region worldwide [4], which makes its use the most common in Peru compared to other construction elements such as wood, adobe, drywall, or metal structures [3], thus increasing the practicality of cement in the use of texture.

Specifically, the texturing process does not have a specialized machine. Some machines perform processes before this, such as portable plastering machines, which increase the efficiency of the covered area from 5m^2/hour using a trowel, to 30m^2/hour using a machine [5]. Next, the walls are plastered, by using a machine with two support columns, a large part of the wall surface is covered, and this saves time and money, in addition to improving the quality of the plaster [6]. Finally, the texturing is executed, unfortunately, there is currently no mechanism to perform this process. The objective of this research is to provide a conceptual design of a lightweight machine with a variable control for the texturing of concrete walls in Peru using silicone molds, thus improving the texturing process. The following sections of this research will describe the design methodology, mechanical and control system, simulation of both systems, and conclusions.

II. METHODOLOGY

The VDI 2221 methodology [7] was chosen because it complies with the ideal sequence to achieve the conceptual design of the lightweight machine, starting with the list of requirements, conceptualizing the solution designs according to the black box and function structure, defining each solution in the morphological matrix and selecting the ideal model based on technical and economic criteria. The sequence of phases of the VDI 2221 methodology is shown in Fig. 1.

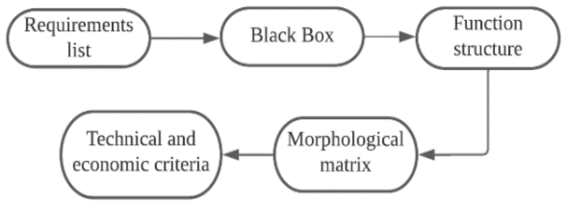

Figure 1. VDI 2221 methodology process.

To identify the optimum solution, the requirements list that the machine must meet is described, ending with the selection of the next requirements:

- A lightweight machine capable of achieving optimum stamping force for the selected textured design is required.

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- To have an electronic speed control system with a digital display for real-time data visualization so that the operator can have a better overview of the work and see the current measured value together with the light signals [8].
- The lightweight machine must be designed so that the manufacturing can be carried out in any workshop with normal equipment [9], also the machine parts in contact with the concrete must be made of moisture and corrosion-resistant material, considering the conditions of the working environment, geometrical dimensions, and manufacturing costs [10].

A. Operations Diagram

Following the methodology VDI 2221, it was proposed to define the inputs and outputs of the system. The inputs are 220vAC power supply, texturing mold coupling, and stamping speed. Likewise, the outputs are speed and power information displayed on a screen, textured design, noise, and vibrations.

Defining the function structure, the main function of the lightweight machine is to perform a linear motion in the form of stamping where the speed and force are to be controlled by a variable speed drive, together with the information displayed on a digital display. In Fig. 2, the operating structure of the lightweight machine is specified.

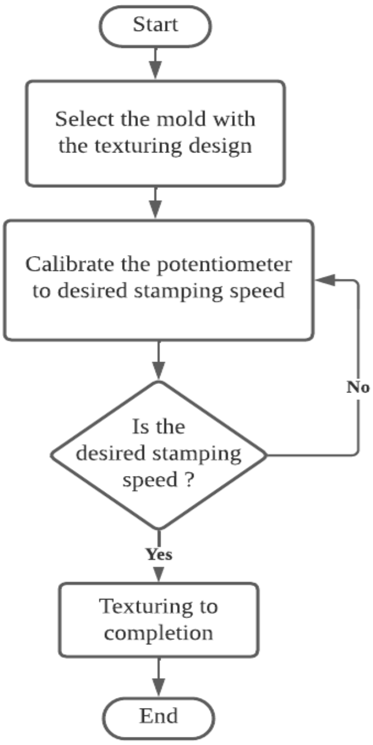

Figure 2. VDI 2221 Operations diagram.

B. Morphological Matrix

The morphological matrix seeks a synthesized approach of various solutions as proposed in the VDI 2221 design methodology [11]. In Table, I, three solution designs with their respective functions were proposed.

TABLE I. MORPHOLOGICAL MATRIX

Main Functions	Solution 1	Solution 2	Solution 3
Power supply	AC power	DC power	Photovoltaic energy- Air compressed
Control process	Arduino Uno	PIC	Nano PLC
Data display	HD44780	GLCD128x64	LCD 4x20
Speed variation	Motor speed controller module PWM	Variable speed drive DC circuit	Pressure relief valve
Mechanical power Supply	DC motor	Pneumatic motor	Universal motor
Machine drive	Push button	Switch	Foot pedal
Linear motion mechanism	Cam mechanism	Slider-crank mechanism	

The solutions are then scored by employing the technical and economic criteria [11] so that it is better defined which is the prototype that meets the expectations and requirements. Fig. 3 shows that solution 1 is the closest to the ideal alternative, so it was chosen to carry out the conceptual design.

C. Definition of the Optimal Solution

Solution 1 makes use of Alternating Current energy to obtain sufficient stamping force, the control system is realized by PIC 18f2550 which displays the selected parameters in a 2x16 LCD, and the stamping speed variation is regulated by a PWM speed module with a rotary switch knob, for the movement the slider-crank mechanism is used, and it is driven by a universal motor. Lastly, an on/off switch for the lightweight machine.

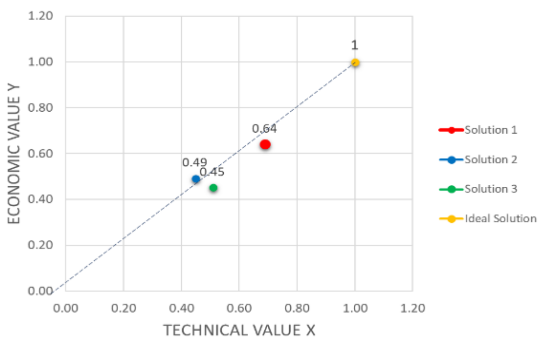

Figure 3. Technical and economic criteria.

The exterior conceptual design of the lightweight machine was drawn in Autodesk Inventor software; in Fig. 4 the 3D modeling can be seen. The machine has a silicone-based texturing mold so that various texturing patterns can be designed to suit the user (1). For a strong grip of both hands, a lateral and central handle is used (2,3), a switch to on/off the lightweight machine (4) and depending on the status the color of the LED changes (5). To modulate the speed a dual channel potentiometer is used which rotates utilizing a rotary switch knob (6), finally, the system parameters are displayed on an LCD screen (7).

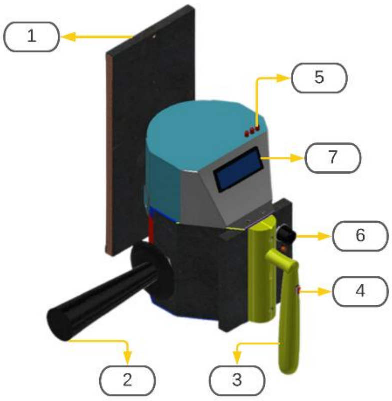

Figure 4. 3D design in Autodesk Inventor software.

The number of different types of texture varies according to the shapes to be drawn on the silicone molds, the most popular being abstract, woody, frosted, and rocky. Fig. 5 shows the silicone mold ready to be attached to the light machine.

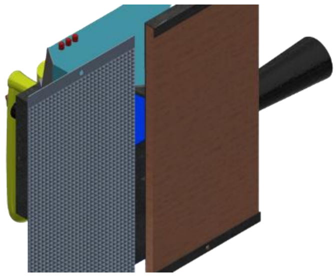

Figure 5. Silicone mold ready to be attached.

Table II shows the main components of the light texturing machine and their respective applications and characteristics, selected to obtain maximum operating efficiency.

TABLE II. COMPONENTS AND FEATURES

Components	Application	Features
LED's	Light signal	3v DC
LCD [12]	Information display	16x2 characters
Dual channel potentiometer	Power Electronics	Doble handling
Universal engine	Mechanical power	150 watts – 1000RPM
Motor speed controller PWM [13]	Varying the speed	Vin=220v CA, Vout=50v-220v AC
Steel 1020 [14]	Driveshaft	Ø=7 mm, L=50 mm
Galvanized steel	Machine cover	Moisture and corrosion resistance
PIC 18F2550 [15]	Electronic system control	Analog-to-digital converter
Stainless steel piston AISI439 [16]	Mechanism plunger	Resistance to friction and high temperatures
Bronze shaft sleeve ASTM B505 [17]	Piston bracket	Tensile resistant

D. Mechanical System

For mechanical power supply, a universal motor was selected, driving the slider-crank mechanism, the free-body diagram of it is shown in Fig. 6. Point A is the axis of rotation of the mechanism, B is the eccentric axis of the pulley end and at C the linear motion of the piston is concentrated. The translational velocities, Vb and Vc, are calculated to determine the angular velocity at point B of 40.62 rad/s. Finally, the linear velocity at point C of 2.52m/s is obtained, which when exerted by a motor power of 150w determines the piston stamping force of 58.42 N, with it the analysis of the motor shaft is determined.

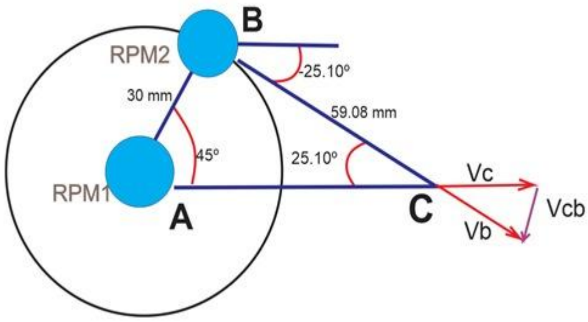

Figure 6. The free-body diagram of the slider-crank mechanism.

The shaft is attached to an internal bearing of the motor, at the top the shaft is anchored to the pulley of the slider-crank mechanism which supports a load of 175.26 N, resulting from the product of the stamping force and the safety factor. The Von Mises stress analysis [18] abbreviated in Eq.1 was used to determine the shaft diameter.

$$\frac{Sy}{Fs} = \sqrt{\left(\left(\frac{32 * M}{\pi * d^3}\right)^2 + 3\left(\frac{16 * T}{\pi * d^3}\right)^2\right)} \quad (1)$$

Where "T" is the torque on the pulley equal to 1.66 Nm and "M" is the maximum moment equal to 8.4 Nm. The material selected for the shaft is 1020 steel since it is highly efficient against repetitive or fluctuating stresses in intense work environments [14], "Sy" is the creep resistance of this selected material equal to 393 MPa, likewise "Sult" is its ultimate tensile stress equal to 469Mpa. "Fs" is a shaft safety factor assigned by designers equal to 1.5. Finally running the equation, we obtain "d" the shaft diameter equal to 6.9mm approximating to 7mm shaft for design purposes.

E. Control System

An AC power supply to 5v DC was used to power the control system controlled by the PIC18F2550. This provides a stable power input to the PIC for proper programming of the data display on the LCD. The dual-channel potentiometer for the analog input of the PIC controller operates at a frequency of 4Mhz and configures the ADC [15] of the PIC18F2550 according to Table III.

TABLE III. CONFIGURATION PARAMETERS

N°	Parameters
1	Analog-to-digital conversion without reference voltage.
2	Configuration of Port AN0 as analog input for conversion.
3	Define 4TAD as the acquisition time. 1TAD=1µs
4	Define 4Tosc as the TAD duration. 1Tosc=1/4Mhz=0.25µs.

In Fig. 7 The logical sequence of operation of the PIC18F2550, which is normally programmed in assembly language, is explained. Due to the flexibility and ease of programming, the MikroC for PIC software [19] software, which works in C language, was used to carry out this logic sequence.

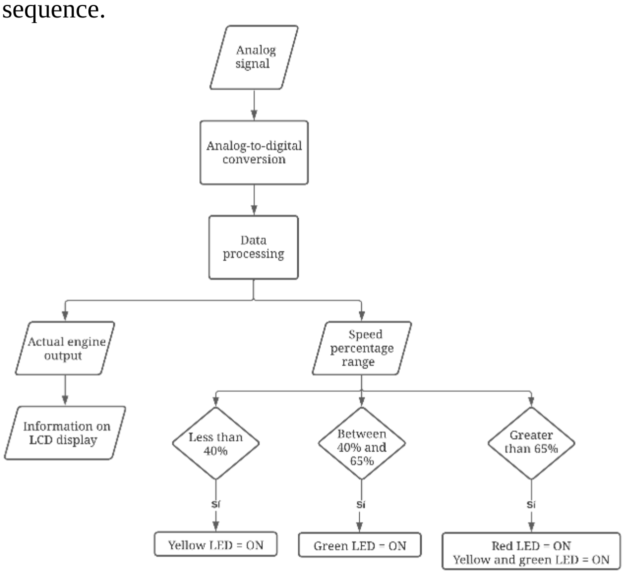

Figure 7. Logical sequence.

In the control system, the necessary parameters were configured and defined for the correct visualization on the LCD screen shown in Table III utilizing the PIC 18f2550. Fig. 8 shows the power and speed of the motor. These parameters are updated instantly by turning the rotary switch knob of the dual channel potentiometer to vary the motor speed.

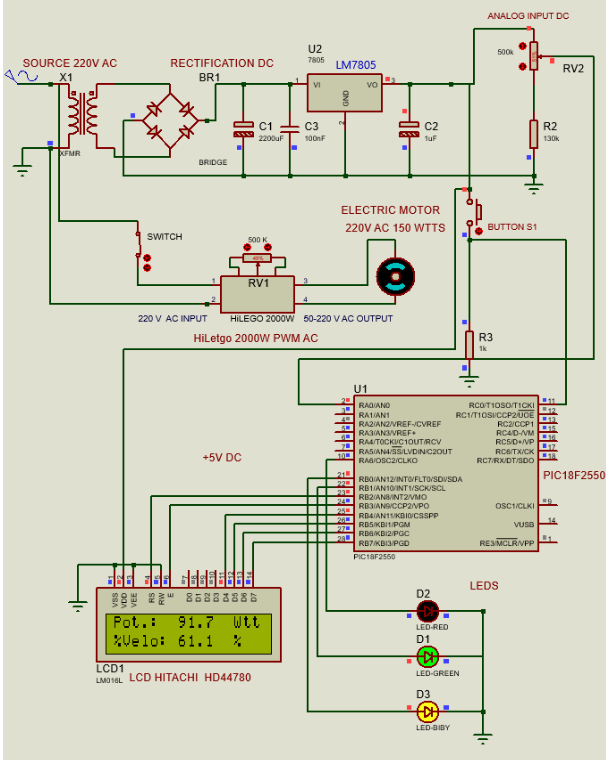

Figure 8. Control System simulation in Proteus 8.1.

III. RESULTS AND PERFORMANCE

A mechanical stress simulation was conducted to determine the optimum performance of the shaft and pulley of the slider-crank mechanism, in which Fig.9 shows that the load is uniformly distributed around the shaft, without fatiguing the component, the load of 175.26 N was applied to the mechanism.

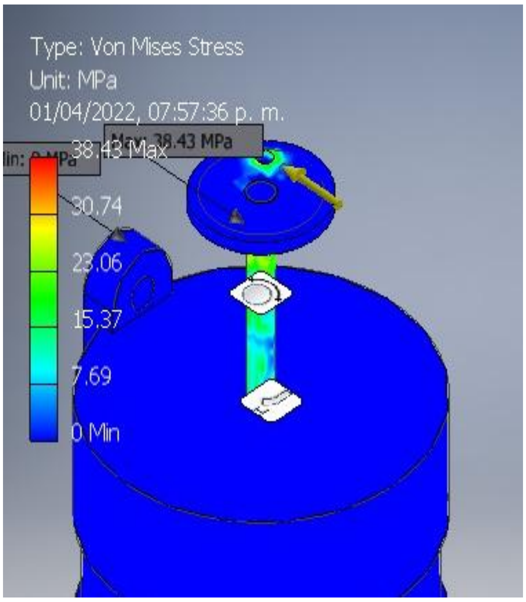

Figure 9. Mechanical stress simulation in Autodesk Inventor software.

Table IV shows the data from the mechanical stress simulation of the lightweight texturing machine in Autodesk Inventor software.

TABLE IV. MECHANICAL SIMULATION DATA IN AUTODESK INVENTOR SOFTWARE

Name	Minimum	Maximum
Volume (mm^3)	515384	
Mass (Kg)	4.05607	
Von Mises stress (MPa)	0.0000361639	38.4286
1st Principal Stress (MPa)	-14.3667	54.2058
3rd Principal Stress (MPa)	-58.7363	10.8904
Displacement (mm)	0	0.0272086
Safety Factor	6.60966	15

Table V shows the main values of Table IV, compared with the design values of Eq. 1, in the result the principal stress is 54.21 [Mpa], much lower than the yield stress of the selected material and with a safety factor greater than 6, which guarantees an optimum real performance of the mechanism.

TABLE V. COMPARISON BETWEEN SIMULATION VALOR AND DESIGN VALOR

Name	Simulation valor	Design valor
Von Mises Stress (MPa)	38.43	Sy=393
1st Principal Stress (MPa)	54.21	Sult= 469
Safety Factor	6.60 - 15	1.5

To establish the effectiveness of the light texturing machine, the texturing mold support was designed to be 258 mm long and 125 mm wide, the maximum speed provided by the control system is 387 RPM and a minimum of approximately 87 RPM. The time varied concerning the type of texturing, for a better understanding of the performance, the times are detailed in Table VI.

Fig. 10 shows the frosted texturing on the left and woody texturing on the right, which is more tedious to perform traditionally.

Figure 10. Frosted and woody texturing respectively.

Using the data collection technique, an independent master builder named Juan de Dios Valencia Ramos, DNI 20064260, with more than 8 years of experience as, a specialist in large-scale civil works such as taps, buildings, and warehouses, was interviewed. The data collected are shown in Table VI.

Using the lightweight texturing machine, for the frosted texturing, the mold must be pressed on the surface for approximately 5 seconds, in the same way, to cover $1m^2$, this routine must be performed 31 times until covering the entire surface, adding maneuvering time and cleaning the mold with water for approximately 2.5 min. For woody texturing, the cleaning time increases to 7 min. Table VI shows the detailed comparison of the performance of the light machine and the construction operator based on the frosted and woody texturing.

TABLE VI. CONCEPTUAL DESIGN AND TRADITIONAL WORK PERFORMANCE

Frosted texturing performance		
Parameters	Conceptual design	Traditional work
Mortar quantity per $1m^2$ (m^3)	0.021	0.021
Working time per $1m^2$	5 Minutes	20 Minutes
Number of coating passes	1	2
Texturing quality	Uniform	Operator skill
Woody texturing performance		
Parameters	Conceptual design	Traditional work
Mortar quantity per $1m^2$ (m^3)	0.03	0.03
Working time per $1m^2$	7 Minutes	25 Minutes
Number of coating passes	1	1
Texturing quality	Uniform	Operator skill

In this way it is possible to appreciate the effectiveness in the speed of the machine to perform the texturing work time 4 times less than traditional texturing, it is fixed in a single repetition and by making use of silicone molds, the quality of texturing is high and is not limited by the skill of the operator, fulfilling the function of beautifying the walls.

IV. CONCLUSIONS

A light texturing machine was conceptually designed with speed variation to suit the operator using a PWM module and visualization of the current working parameters using a PIC 18F2550 controller, due to its versatility and low cost, working in parallel with Alternating Current and Direct Current energy, because of the implementation of the dual channel potentiometer.

Based on the results obtained in the analysis of the mechanical and control system, it is verified by employing simulations, that the connecting slider-crank mechanism was designed with 1 degree of freedom so that the lightweight machine for texturing only performs a linear stamping movement, moreover, the 220v AC power supply is ideal to feed the 150 watts' motor, and when rectified, to supply the controller and its electronic components.

The exterior components of the lightweight machine for texturing are resistant to corrosion and humidity of the working environment, so galvanized steel is used for the light machine case, AISI 439 stainless steel for the piston, and ASTM B505 for piston bronze shaft sleeve

The working times vary depending on the design of the texturing, in abstract texturing is much less than predefined texturing such as woody or rocky, giving more versatility to the light machine to make use of predefined molds. For this type of more complex texturing, a larger scale mold could be coupled for a better appreciation of the customer.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

All authors contributed to the design of the lightweight machine in this research. Alan Ojeda performed all the mechanical and stress simulations, as well as gathered performance data from the conceptual design and traditional work. Manfrin Antialon contributed to developing the methodology, defining the optimal design of the machine, and collecting the necessary theoretical information. Both authors elaborated on electrical design and PIC programming. Professor Deyby Huamanchahua contributed in general all the background knowledge and advice necessary for the elaboration of this scientific article.

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