DEVELOPMENT OF A STATOR DRYING MACHINE APPLIED TO THE OIL INDUSTRY

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ABSTRACT

Stator drying is a process carried out in the repair of induction motors used in the oil industry. In this work, the development of a stator drying machine is proposed to have greater efficiency in the number of repaired motors to be put into service. The offered stator drying machine is robust and has electronic elements that support high current levels, such as SCR (Silicon Controlled Rectifier) used in power electronics. Power control is obtained by on-off control. In the SCR trigger control stage, a central device called Raspberry Pi is used. The user interface is an LCD screen (Liquid Crystal Display) that connects to the Raspberry Pi via USB port and communicates via serial. As a result, the drying time motor is less; and the number of stators ready to be put into operation is increased.

Keywords: motor, SCR, Raspberry Pi, drying, stator.

1. INTRODUCTION

In the oil industry, several companies are dedicated to equipment maintenance and repair to extract oil in their clients' oil fields. The electric motor is a fundamental part of the electro-submersible pumping system; its beginnings date back to 1911 when the company "Russian Electrical Dynamo of Arutunof" operated the first submerged motor in an oil well (Hirschfeldt and Bertomeu, 2014). These motors are responsible for providing the electrical energy necessary for the system's operation. Three-phase induction motors are the most used in industrial electric drives (Jaramillo-Matta *et al*., 2011). Engines are tested to ensure they meet minimum performance criteria to be shipped to field service. The tests carried out on these motors measure the motor winding state and the resistance at maximum operating levels, under IEE 43-2000 and IEEE 95-2002 standards (Fernández Daher, 2005).

Service companies measure their production rates according to performance and efficiency in each of their areas. The development of a stators drying machine is proposed to increase the number of motors with optimal characteristics to be put into operation.

The proposed stator drying machine is robust and has electronic elements that withstand high current levels, such as SCRs used in power electronics. Power control in direct current circuits is obtained by varying the device's duration on and off times. This mode of operation is called on-off control or cut-off control. Currently, SCRs with a current-carrying capacity from 0.25 to 2000 A are manufactured to operate with voltages of about 2600 Volts (Valencia Gallón, 2013). For the machine's power stage, a control stage is required; in this case, a SCRs trigger control for which a central device called Raspberry Pi is used, which with a suitable configuration carries out each of the drying processes stators.

2. MATERIALS AND METHODS

The stator drying machine development comprises of several stages, each with a specific function that contributes to the final result shown in Figure-1.

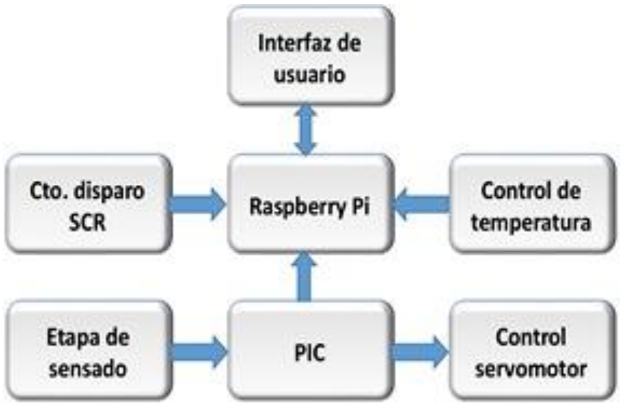

Figure-1. Stator drying machine general structure.

2.1 Stage of Sensing and Sending Data

2.1.1 Current transducer

The source used to supply current is an inverter machine for electric welding that provides up to 400 Amps. It also includes a current transducer used to obtain the current value delivered to the stator.

It is necessary to know the current value that the machine's power source can supply to control the electric current which each of the stators' drying process is carried out. A Current Transducer (CT) integrated with the source is used. The CT is an element that measures electrical current. The output delivers a DC voltage signal (Direct Current), which must be interpreted to obtain the sensed current value.

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2.1.2 Sensed signal conditioning

The drying electrical machine diagram is shown in Figure-2. The power source used in the stator drying machine has a control card whose output delivers a voltage with a variation of 0.01 volts for each supplied ampere.

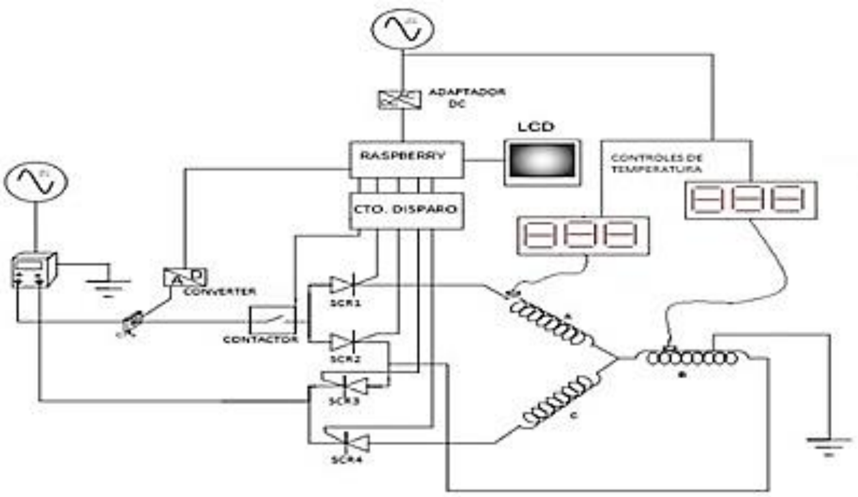

Figure-2. Drying electrical machine diagram.

The motors on which it works reach a maximum of 150 amps and the voltage variation that the control card will have is in a range between 0.2 and 1.5 volts.

The PIC (Programmable Integrated Circuited) 18f452 microcontroller (Microchip, 2019) is necessary to achieve this reading in the control device. Perform an analysis to obtain the best range and the highest efficiency to use the largest number of bits, with whom the PIC works. The PIC microcontroller is used to adapt the input voltage signal, convert this signal into digital, and carry out operations. The test results with unamplified input voltage and amplified input voltage are presented in Tables 1 and 2.

Table-1. Test with unamplified Vin.

Vin	Gain	Vin	Data dig (Vref:5) (10bits)	Aprox.	Data dig (Vref:5) (8bits)	Aprox.	Data dig (Vref:1,6) (10bits)	Aprox.	Data dig (Vref:1,6) (8bits)	Aprox.
0,2	3	0,6	40,96	41	10,24	10	128	128	32	32
1,5	3	4,5	307,2	307	76,8	77	960	960	240	240
			Spam	266	Spam	67	Spam	832	Spam	208
			Spam use (%)	26%	Spam use (%)	26%	Spam use (%)	81,25%	Spam use (%)	81,25%

Table-2. Test with amplified Vin.

Vin	Gain	Vin	Data dig (Vref:5) (10bits)	Aprox.	Data dig (Vref:5) (8bits)	Aprox.	Data dig (Vref:1,6) (10bits)	Aprox.	Data dig (Vref:1,6) (8bits)	Aprox.
0,2	3	0,6	122,88	123	30,72	31	384	384	96	96
1,5	3	4,5	921,6	922	230,4	230	2880	2880	720	720
			Spam	799	Spam	200	**Spam**	2496	**Spam**	624
			Spam use (%)	78%	Spam use (%)	78%				

The digital input data used to calculate the maximum range of use is found, as shown below.

$$Dato_{in} = \frac{V_{in} * 2^n}{V_{ref}}$$

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Table-1 shows that working with the amplified input voltage cannot use a reference voltage lower than the maximum input voltage present. The digital data would exceed the highest number allowed, either 256 or 1024, depending on the number of bits chosen for the ADC work (Analog to Digital Converter) in the microcontroller.

After the results, it is decided not to amplify the input voltage that reaches the PIC. This device has the possibility of configuring a reference voltage that helps to reduce the input range to make the most of all the bits of the ADC. As mentioned before, the input range in volts varies between 0.2 and 1.5. A range of digital values between 128 and 960 working with the 10-bit ADC and a reference voltage of 1.6v is obtained.

Considering that n = 10 since they are 10 bits for the ADC, the resolution is obtained as follows.

$$Res = \frac{V_{ref}}{2^n} = \frac{1.6v}{1024} = 1.5625mv$$

2.1.3 Sending data to the Raspberry Pi

The PIC has an ADC input through which it takes the voltage that indicates the current value provided by the motor. The reading of this signal is stored as digital data to obtain later the current information that is being sensed as follows:

$$V_{in} = ADC * \left(\frac{V_{ref}}{1024}\right) * 100$$

The sending of data to the Raspberry Pi is done through serial communication and the data sent is string type where two flags are used whose function is to identify the beginning and the end of the value sent.

2.2 Servo Motor Control

The potentiometer regulates the current output on the power source. The servo motor controls the potentiometer shaft to vary according to the desired value of current. Through the PIC, the servomotor is controlled using a timer. The train of pulses is obtained that places the axis in the indicated position. The servomotor used in the project works with a high pulse duration between 0.5 and 2.5 ms and with a low pulse duration of 20 ms.

The PIC has a timer overflow interrupt function called "Timer0", which is 8 bits long, and the duration to execute an instruction is four clock cycles. The Timer0 timeout is calculated as follows:

$$T_{desborde} = \left(\frac{4}{FOSC}\right) * (Preescaler) * (2^n - TMR)$$

FOSC is the Oscillator Frequency, *Preescaler* is the number of times the oscillator frequency divides, *n* is the number of bits used in the timer, and *TMR* is the jump the timer will start. Then,

$$T_{desborde} = \left(\frac{4}{4*10^6\,Hz}\right) * (16) * (2^8 - 0) = 4.096ms$$

In other words, every 4.096 ms, the Timer0 overflows, so to reach 20ms, it is calculated how many times the timer should overflow and try to give the highest possible accuracy. Then the Timer0 must overflow 4.88, and taking into account that the Timer0 timer is 8 bits, each jump has a duration of:

$$Duración_{salto} = \frac{4.096*10^{-3}}{256} = 16*10^{-6}\,s.$$

Now, to calculate the jump in which the Timer0 timer should start in overflow 5. A duration of 5 overflows of Timer0 uses 20.48ms; that is, 0.48ms are eliminated so that the overflows last the 20ms that are needed. It is known that each jump lasts 16µs, so the value of the jump from which it must start is calculated as follow:

$$Salto_{inicio} = \frac{0.48*10^{-3}\,s.}{0.016*10^{-3}\,s.} = 30$$

The pulse width for servo motor operation must be between 0.5ms and 2.5, ms indicating 0° and 180° respectively, so

$$Salto_{0^\circ} = \frac{0.5*10^{-3}\,s.}{16*10^{-6}\,s.} \cong 31$$

$$Salto_{180^\circ} = \frac{2.5*10^{-3}\,s.}{16*10^{-6}\,s.} \cong 156$$

The previously found values are used to make comparisons with the value of Timer0 and thus know the maximum value and the direction of servomotor shaft rotation.

2.3 PIC Connection

PIC is the element in charge of taking the voltage values, executes the programming, sends the data to the Raspberry Pi, and then controls the servomotor position. The connection diagram is shown in Figure-3.

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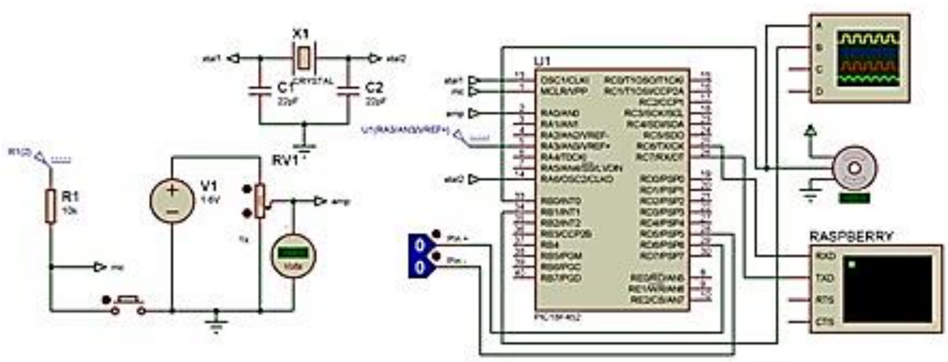

Figure-3. PIC connection diagram.

2.4 User Interface

The user interface, as shown in Figure-4, allows the stator drying machine management, designed with the Workshop program of the company 4dSystems (4DSystems, 2019). The screen is a 7-inch resistive touch screen. From it, the time is configured. The pulses are sent to control the position servo motor and establishes communication with the Raspberry Pi to have the phase control. On this screen, the phases through which the current is flowing are visualized using LEDs. There are also buttons to navigate between forms, elements that send the data to the Raspberry Pi, and digital outputs connected to the PIC that serve to control the servomotor position.

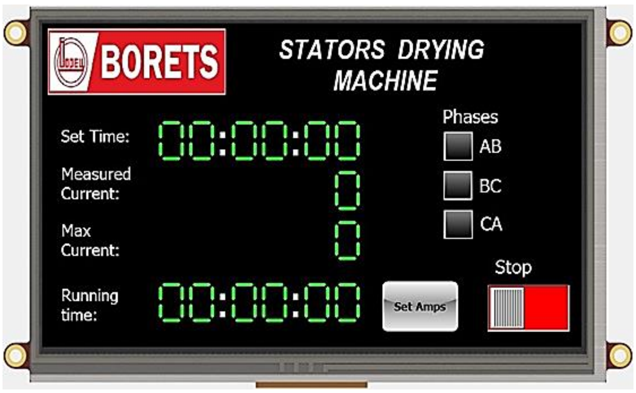

Figure-4. The user interface.

2.5 Temperature Control

The stators subjected to drying with the machine operate at a maximum temperature of 135 °C to avoid damage to each coil. To protect the stators from faults due to excess temperature, two On/Off type temperature controls are used, configured with the maximum value that a stator can reach. Two temperature controls model, TC4S-14R (Autonics, 2019) are used, which has a 4-digit display. This control connects to a type J thermocouple attached to the stator to sense it during the drying time.

2.6 SCR Trigger Circuit

An SCR is chosen because they withstand high currents and conduct in only one direction to avoid faults and short circuit accidents. Optocouplers and relays are used in the SCRs trip circuit design because it is necessary to have the digital circuit isolated from the power circuit, as illustrated in Figure-5. Relays are inexpensive electromechanical elements used to trigger each of the SCRs. When the SCRs work in direct current, they remain locked as long as the current flowing through them is more significant than each maintenance current.

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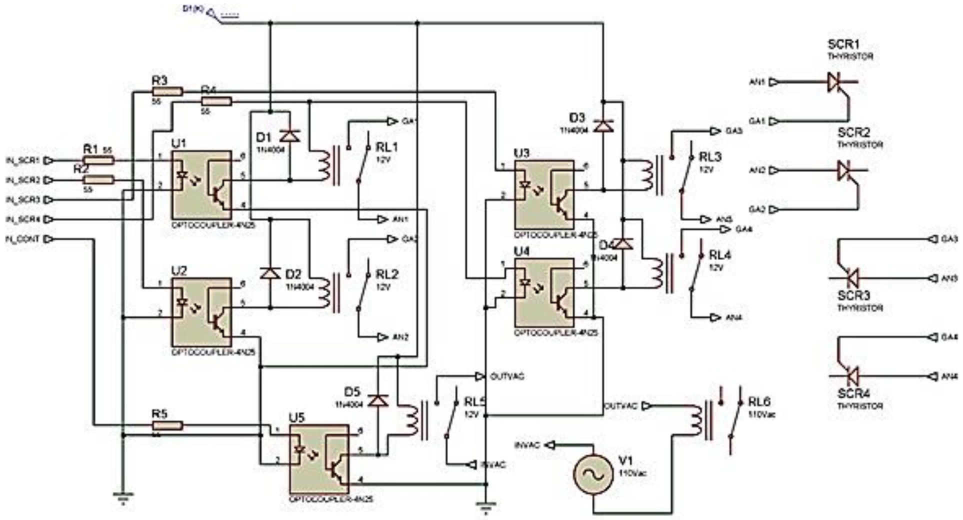

Figure-5. SCR trigger circuit.

The stator drying machine works with a switching control between phases in a cyclical process for about 4 hours because the motors are three-phase. The optocouplers are triggered using a pulse from the GPIO port (General Purpose Input / Output) of the Raspberry Pi. Each pair of phases is being controlled for a specific time, and the SCRs must be unlatched in conduction through a solid-state contactor.

2.7 Raspberry Pi

This device establishes direct communication with the PIC and the LCD screen through the USB ports using the rs232 serial protocol. The sending and receiving of data are configured. The Raspberry Pi works with a timer in real-time to carry out the number of cycles required during the drying process of a stator.

The programming language used is Python. The facilities it offers are free software because the libraries can be modified by the same users and adapted to their applications.

The Raspberry Pi uses the GPIO port for the digital outputs and delivers a voltage output of 3.3v as logic level 1 and 0v as logic level 0. Through an adaptation made to the library written in C language provided by the manufacturer of the 4Dsystems screens, the Raspberry Pi can read the value of each of the objects located there.

3. RESULTS AND DISCUSSIONS

A stator drying machine is designed and implemented, as shown in Figure-6. The device has a current capacity of 150 amps, sufficient for optimum stators drying. The uniform drying of the stators is achieved by the switching control of their phases using the SCRs and the Raspberry Pi.

Figure-6. Stator drying machine-implemented.

Insulation is a fundamental parameter to consider when evaluating motor quality, and this factor is considerably improved with the completion of this project. The respective Megger demonstrates this, and Hipot tests results (Zuñiga Kalab, 2019) carried out on the motors according to the IEEE 95 standard, which establishes the type of tests carried out on electrical equipment to evaluate the status of their inductors and their insulation capacity.

In addition to the quality improvements, a significant improvement in drying time was achieved, approximately 8 hours; one stator was dried per working day. After the stator development drying machine, the drying of 2 stators is carried out in 8 hours, representing double the production and generating more significant sales and better income.

The machine has a user-friendly interface, uses new technologies, and facilitates interaction with other devices thanks to its digital outputs.

Finally, a machine to provide solidity and confidence is developed. Also, its robustness and the excellent design of each of its stages is presented.

4. CONCLUSIONS

Engines extend their useful life when they are put to fair use and undergo a satisfactory repair process that meets the quality standards of the companies and customers they serve.

With the insulation and Hipot tests, the response capacity is established against maximum working conditions. The short circuit risks are prevented when put into operation since this could stop the process in an oil well.

The decrease in drying time and the increase in the number of stators ready to be put into operation significantly increases the production indicators and improves the motor's quality. Consequently, representative economic income is generated for companies.

The insulation of the motor was increased. Before the machine development, drying generated up to 50GΩ in a time of 8 hours. After the machine's implementation, approximately 85GΩ was achieved in a time of 4 hours of drying. This result indicates that better drying is performed in the stator and higher dielectric strength in the coils.

With new technology elements, it was possible to create a robust, easy-to-use machine that meets all protection and current capacity requirements for drying the stators with which companies in the oil sector work.

The stator drying machine is designed with a current capacity of 150 amps, not to exceed costs, since that current is sufficient to perform an optimal drying.

ACKNOWLEDGEMENTS

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