Inform: Jurnal ilmiah Bidang Teknologi Informasi dan Komunikasi
Vol.7 No.2 July 2022, P-ISSN: 2502-3470, E-ISSN: 2581-0367

Design of Prototype Load Moment Indicator on Mobile Crane using Microcontroller based on Lifting Load Chart

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Received: 2022-06-30; Accepted: 2022-07-22; Published: 2022-07-30

*Abstract***—** A load moment indicator (LMI) is an electronic device on heavy equipment cranes that can provide information and a warning system to operators in the event of an overload during the lifting load process. This tool has a very important role because it provides accessible information to the operator about the safe working load (SWL) that the crane can lift. Mobile cranes have a high accident potential when compared to tower cranes, and this is because mobile cranes have high mobility. In this paper, a prototype LMI has been made on a mobile crane based on a microcontroller that can provide value. The method used is an algorithm to find the closest value from the lifting load chart of a crane car. The programming algorithm is still manual, namely by equating and comparing boom crane conditions such as boom length, boom angle, and radius contained in the lifting load chart with the results of measuring boom crane conditions by sensors. The nearest value search algorithm follows the rules of how to read the mobile crane lifting load chart. The test results show that the sensors used to measure boom length, boom angle, and actual load each have a maximum relative error of 0.92%, 8%, and 4%, respectively. Meanwhile, to find the SWL value, the comparison scanning method can provide the SWL value according to the lifting load chart of the mobile crane. It can provide accurate information on whether the lifting load process is safe or overloaded.

Keywords— Mobile Crane, Lifting Load Chart, LMI, SWL, Boom Angle, Boom Length.

I. INTRODUCTION

Heavy equipment such as cranes is often used in port, construction, and industrial projects that can be used to lift heavy objects horizontally and vertically [1]. There are several types of cranes, such as bridge/overhead, barge lift, tower crane, and mobile crane. Mobile crane is widely used in construction projects because it has high mobility compared to tower cranes [2]. Mobile cranes have similarities with vehicles or trucks, but the difference lies in their characteristics and functions. Mobile cranes have a high accident potential [3][4]. According to [5], accidents reach 72% of all mobile crane users whose main causes are overturning (45%), ground collapse, and overloading. Therefore, the mobile crane operation must be planned in accordance with regulations such as ground contact pressure and crane position while considering productivity and optimal lift plan [6].

Planning safe lifting loads on a mobile crane is determined by several factors such as boom length, boom angle, and working radius [7][8]. Each manufacturer of mobile cranes is required to provide their customers with information in the form of a manual table concerning the safe working load (SWL), also known as a lifting load chart. This is done so that the mobile crane operator, when carrying out a lifting load, must carefully observe the manual table to prevent excess lifting loads that can lead to overloads. Causing the mobile crane to overturn. For the reasons above, this paper proposes an instrumentation tool known as the Load Moment Indicator (LMI), which can predict or provide information about the SWL value based on the lifting load char to the operator. One of the goals is to make it easier for operators to observe SWL so that mobile crane accidents caused by overloading can be avoided. Some mobile cranes with more modern technology are equipped with LMI information technology. However, it becomes an obstacle if construction companies still use or own mobile cranes with SWL table information still in manual form. The proposed LMI design is still in the prototype form, where the lifting load chart data is embedded into the microcontroller so that it is able to determine the SWL value based on the boom length, boom angle and working radius parameters and the system is designed to work in real time.

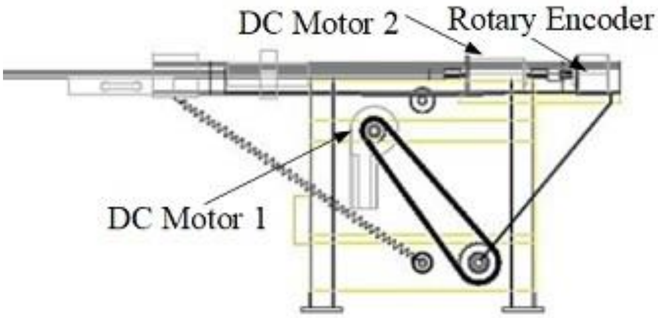
Now days, just few studies talking about safety technology, especially regarding LMI on mobile cranes. In [9], an analysis of the occurrence of mobile crane overturns has been carried out but the overall analysis is carried out on the causes of mobile crane overturns and is carried out in a simulation using the Genetic Algorithms (GA) method. The stability of the mobile crane has also been carried out by [10] during the lifting load process, but only focused on ground contact stability analysis. The ease of operators in obtaining information on the condition of the mobile crane which is displayed in the crane modeling (virtual 3D) when carrying out lifting load operations has also been carried out [11], however, only crane activities such as boom length, boom angle and lifting load are displayed. Information to get the SWL value can be done by mathematical modeling of the mobile crane, but this method is difficult to implement because it really depends on the construction parameters of the mobile crane itself [6][12]. From several previous studies on the safety of mobile cranes, the method proposed in this

DOI: http://dx.doi.org/ 10.25139/inform.v7i2.4746

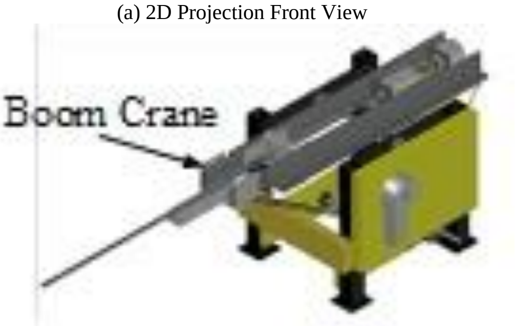
paper in determining SWL is to use an algorithm to find the nearest value from the mobile crane lifting load chart. The programming algorithm is still manual, namely by equating and comparing boom crane conditions such as boom length, boom angle, and radius contained in the lifting load chart with the results of measuring boom crane conditions by sensors. The nearest value search algorithm follows the rules of how to read the mobile crane lifting load chart.

II. Research Methodology

The design of the mobile crane mechanical prototype is shown in Figure 1, where each boom angle and boom length can be adjusted using a DC motor. The prototype mobile crane design that will be made can only move the boom crane, but the mobile crane body cannot move like a real mobile crane. To change the length of the boom crane, DC motor one is driven Clockwise (CW) or Counter Clockwise (CCW). While the direction of rotation of the DC motor two is used to adjust the angle of the boom crane.



(a) 2D Projection Front View



(b) 3D Isometric Projection
Figure 1. Design Of a Mobile Crane Prototype

The design of the LMI hardware block diagram in this study is shown in Figure 2, where the input side consists of two parts, the first is the input from the sensor, and the second is the input data from the computer. The sensors used to consist of three types: a rotary encoder used to measure the boom length, a load cell used to measure the load being lifted, and a potentiometer used to measure the angle of the boom. While the computer is used to enter data from the manual table or to lift the load chart and send it to the microcontroller via serial communication, the microcontroller will store it in the EEPROM memory. Mobile crane condition information such as the weight of the load being lifted, boom length, boom angle, and working radius is displayed on the LCD and computer.

If the lifting load condition exceeds the SWL value, an alarm will give a sound that warns the operator not to continue lifting load activities.

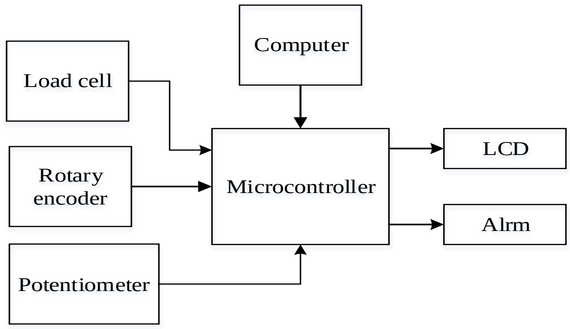


Figure 2. LMI Diagram Block

A. *Load Cell*

The type of load cell used in this study is a single-point load cell with a capacity of 5 kg and an output rate of 2 mV/V in Figure 3.

Figure 3. Single Point Type Load Cell [13]

A signal conditioning circuit or a voltage amplifier circuit is required because the output voltage of the load cell is very low. This is necessary so that the output voltage of the load cell can be read by the ADC microcontroller, which in turn allows for a more accurate reading of the weight of the load being lifted.

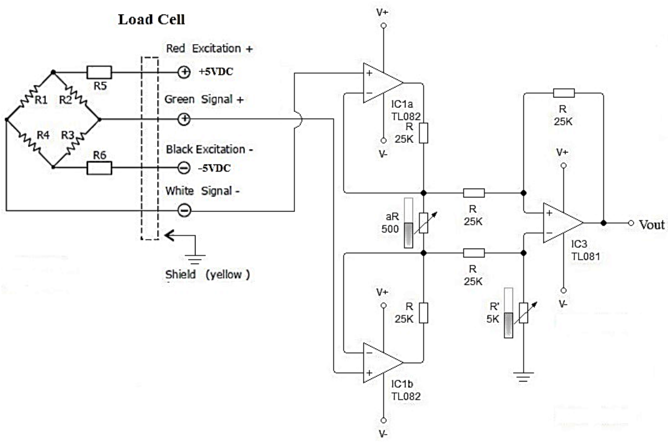


Figure 4. Load Cell Signal Conditioning Circuit

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In Figure 4, the value of the output voltage (Vo) of the load cell amplifier circuit, if it is known that the values of aR=1kΩ and R=25kΩ can be calculated by Equation (1).

$$V_0 = (E_1 - E_2)\left(1 + \frac{2}{a}\right) \tag{1}$$

Where:

$$a = \frac{aR}{R}$$

$$a = \frac{1000}{25000} = 0{,}04$$

If it is assumed that the input voltage $E_1 = 5mV$ and $E_2 = 0.1\ mV$, then the output voltage Vo is calculated using Equation (2).

$$V_0 = (E_1 - E_2)\left(1 + \frac{2}{a}\right)$$
$$V_0 = (5 - 0{,}1)\left(1 + \frac{2}{0{,}004}\right) = 249{,}9mV \tag{2}$$

B. Potentiometer

The potentiometer is used to determine the angle of the crane boom. As seen in Figure 5, the potentiometer's shaft is connected to the rotating shaft of the boom crane. Because of this connection, the potentiometer's resistance value adjusts according to the positional adjustments made to the boom. This change in resistance can be turned into a stress value by utilizing a stress divider formula, the value of which is linearly related to the angle at which the crane boom is tilted.

Figure 5. Potentiometer [14]

C. Rotary Encoder

This study uses a rotary encoder to measure changes in crane boom length. By arrangement, the rotary encoder shaft is connected to the boom crane's threaded shaft, so any changes in boom length can be determined by counting the number of pulses issued by the rotary encoder. Figure 6 is a physical form of a rotary encoder with 360 holes in one full rotation.

Figure 6. Rotary Encoder [15]

D. Lifting Load Chart

The lifting load chart on a mobile crane is a manual table whose function is to guide the operator so that moving or lifting the load does not exceed the allowable lifting load or SWL. An example of a lifting load chart is shown in Figure 7[16], in which boom length parameters, boom angle, operating radius, and SWL value. While Figure 8 is a range diagram that can show determining the crane's most appropriate configuration and positioning [16].

BOOM LENGTH — Maximum Load Chart in pounds (lbs) with fully extended outrigger

OPERATING RADIUS (FT)	27 FT		34 FT		43 FT		52 FT		61 FT		70 FT	
	LOADED BOOM ANGLE (DEG)	LOAD RATING (LB)	LOADED BOOM ANGLE (DEG)	LOAD RATING (LB)	LOADED BOOM ANGLE (DEG)	LOAD RATING (LB)	LOADED BOOM ANGLE (DEG)	LOAD RATING (LB)	LOADED BOOM ANGLE (DEG)	LOAD RATING (LB)	LOADED BOOM ANGLE (DEG)	LOAD RATING (LB)
5	77	34,000*										
10	66	21,100*	71	17,100*	75	16,000*	78	15,700*				
15	54	15,100*	62	14,000*	68	12,100*	72	11,100*	75	10,800*	77	9,600*
20	39	11,100*	51	10,100*	61	9,100*	66	8,600*	71	8,200*	73	7,300*
25	17	7,900*	40	7,700*	53	7,100*	61	6,900*	66	6,600*	69	5,900*
30			23	6,500*	44	6,100*	54	5,600*	60	5,300*	64	4,900*
35					33	4,800*	47	4,700*	54	4,600*	60	4,150*
40					16	3,500*	38	4,100*	48	3,900*	55	3,550*
45							27	3,250*	41	3,200*	49	3,050*
50							9	2,950*	33	2,800*	44	2,650*
55									23	2,500*	37	2,350*
60											29	1,900*
65											19	1,700*
STOWED JIB DEDUCTIONS (POUNDS)	450		360		260		230		200		175	

NOTE: STRUCTURAL STRENGTH RATINGS IN CHART ARE INDICATED WIH AN ASTERISK *

Figure 7. Lifting Load Chart

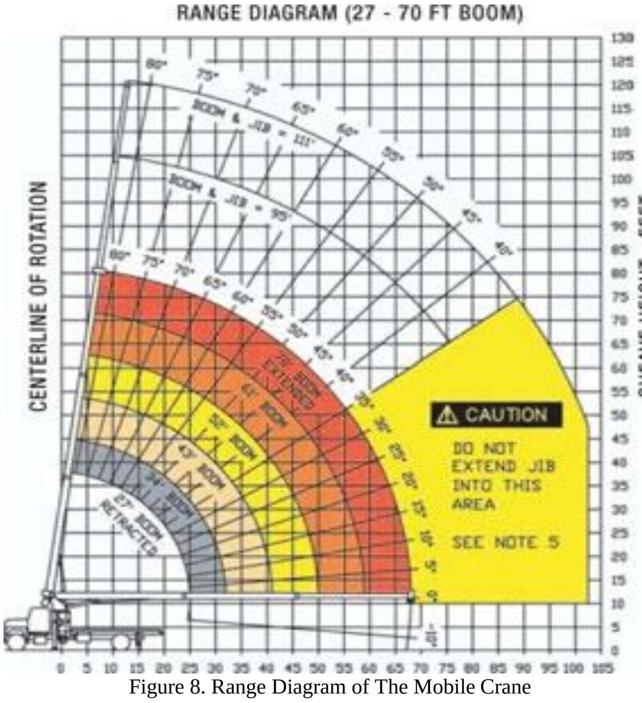

Figure 8. Range Diagram of The Mobile Crane

The SWL value will vary according to the boom length, operating radius, and boom angle parameters. Because the values that are included in the lifting load chart of each crane differ depending on the manufacturer of the mobile crane, in this study, all of the values on the lifting load chart are able to be changed via a computer in order to ensure that the LMI system that was created is compatible with all different kinds of mobile cranes. Figures 7 and 8 show that the larger the

DOI: http://dx.doi.org/ 10.25139/inform.v7i2.4746

boom length and operating radius, the smaller the SWL value; vice versa, the larger the boom angle, the greater the SWL value. However, if the results of the measurement of the condition of the mobile crane do not match the values listed in the lifting load chart, the smallest SWL value will be chosen. The aims to avoid overturns due to overloading[16].

From the description of how to read the mobile crane lifting load chart above and refer to Figures 7 and 8, the sequence of stages used in this paper is as follows [16]:

- Determine the operating radius range with the following example, if the value of operating radius = 20 ft, the boom length is likely to be in the 27-70 ft area.
- Determine the boom length range; with the following example, if the boom length is between 52-60 ft, the boom length range is in the 52 ft area.
- Determine the boom angle range. Since the operating radius = 20 ft and the boom length is in the 52 ft area, the boom angle position is in the 66^O area.
- Determine the SWL value. If all range conditions or boom positions are known, then the SWL value can be learned, which is 8.

To achieve the desired level of performance, it is necessary to test each component of the LMI design that will be made, which includes testing the sensors that read boom length and boom angle. The test is carried out to obtain a good level of accuracy from the sensors to be used. Then proceed with the overall test to find the SWL value with the algorithm according to how to read the mobile crane lifting load chart.

III. Result and Discussion

The prototype load moment indicator (LMI) design on a mobile crane has a maximum lifting load of 5 kg, as shown in Figure 9. To see the performance results of the LMI prototype based on a microcontroller, testing each component and overall testing. Here are some of the test results:

Figure 9. Desain of LMI Prototype On Mobile Crane

A. *Load Sensor Test (Load Cell)*

The load cell test is carried out as shown in Figure 10a, namely by providing a known weight by hanging the load on the load cell attached to the end of the boom crane. Weight tested from 0.5 to 5 kg in increments of 0.5 kg. In this test, the load cell with a voltage output has been calibrated to kg, as shown in Figure 10b. The test results are shown in Figure 11, where the largest relative error value is 4% when the load cell is loaded with 0.5 kg, 1 kg, and 4 kg.

(a) Load Cell Weight Test

(b) Load Cell Calibration Results

Figure 10. Load Sensor Test

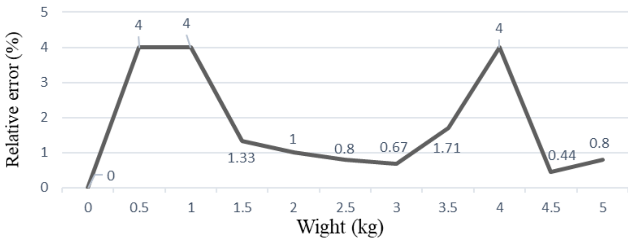

Figure 11. Graph of The Relative Error Load Cell

B. *Boom angle sensor Test (Potentiometer)*

This test aims to determine the potentiometer's accuracy in measuring the crane's boom angle. The test is carried out by comparing the results of the potentiometer calibration with an arc, as shown in Figure 12. The angle tested is 10-60^o with a maximum relative error value of 8% when the angle reading is 10^{o,} as shown in Figure 13.

DOI: http://dx.doi.org/ 10.25139/inform.v7i2.4746

(a) Boom Angle Test

(b) Boom Angle Calibration Results At 60°

Figure 12. The Results of The Potentiometer Calibration

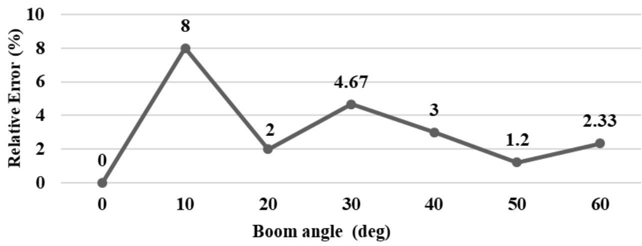

Figure 13. Graph of Relative Error Boom Angle

C. Boom length sensor Test (Rotary encoder)

This test is carried out by counting the number of rotations of the DC motor that moves the thread as a medium for lengthening and shortening the boom crane, as shown in Figure 14.

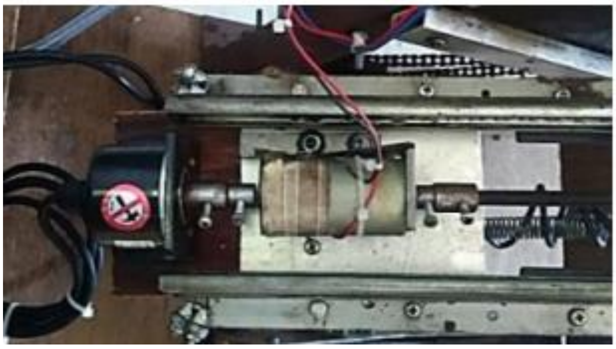

Figure 14. Rotary Encoder Installation

Before getting the difference or error between the reading of the boom length by the microcontroller and the actual length of the boom, calibration is carried out first by counting the number of rotary encoder holes for each 1cm boom length. After the boom length sensor has been calibrated, as shown in Figure 15, an error calculation is carried out to see the accuracy of the rotary encoder in reading the crane's boom length. The relative error is below 1% with a boom length test of 20-60 cm in Figure 16. These results indicate that a rotary encoder with 360 holes can measure boom length with high accuracy.

(a) Boom Length Testing

(b) Calibration Result of Boom Length At 14.5 cm

Figure 15. Boom Length Sensor Calibration

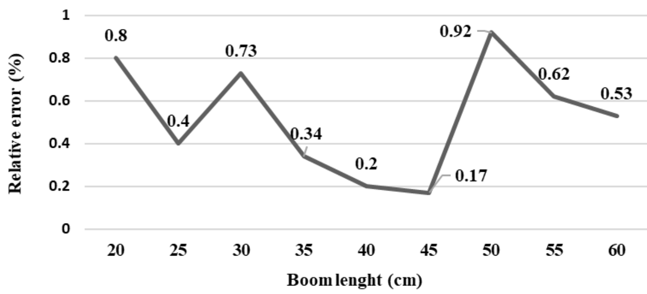

Figure 16. Graph Of the Error Relative Boom Length Sensor

D. Overall Test

Reading the state of the mobile crane, which includes carrying out measurements like measuring the length of the boom and the boom angle, is how the indicator of the overall test of the prototype load moment is carried out. The operating radius, as well as the results of the measurements, will be checked with the lifting load chart that has been entered into the computer. This chart is then saved in the EEPROM memory of the microcontroller. Figure 17 displays the data values found on the lifting load chart used for this test. The

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lifting load chart that was entered into the computer looks like the one that is seen below.

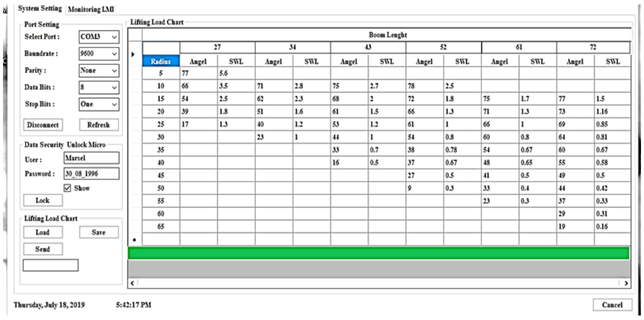

Figure 17. Lifting Load Chart Display on Computer

The first test was carried out with a boom length of 27 cm, a boom angle of 39°, and a lifting load of 1kg. The results are that the SWL value shows 1.8 kg, as shown in Figure 18. If the SWL value is greater than the load being lifted, then the 1kg lifting load is safe to be lifted with a mobile crane. In addition, the test of the lifting load was performed as many as 28 times using various settings for the boom crane, and the results are presented in Table I. According to Table I, if the lifting load is larger than the SWL, the system will provide an overload indicator. This indicates that the operator needs to stop raising the weight.

Figure 18. Mobile Crane Display in Computer

TABLE I
OVERALL TESTING RESULT

Boom Lenght (cm)	Boom Angel (deg)	Radius (cm)	Lifting Height (cm)	Load (Kg)	SWL (Kg)	SF	Indicator
27.24	39.43	21.04	17.3	1	1.8	1.8	Safe
27.24	54.86	15.67	22.28	0.98	2.5	2.5	Safe
27.8	44.53	19.93	19.38	1.47	2.5	1.7	Safe
27.8	29.57	24.18	13.72	1.47	1.8	1.22	Safe
34.89	40.38	26.57	22.61	0.98	1.2	1.23	Safe
34.89	61.71	16.52	30.73	0.98	2.3	2.36	Safe
34.65	30.86	29.74	17.78	1	1.2	1.2	Safe
34.75	38.34	27.25	21.56	1.47	1.2	0.81	Overload
43.02	61.14	20.75	27.68	1	1.5	1.5	Safe
43.02	31.43	36.7	22.45	1	0.7	0.7	Overload
43.02	46.29	29.72	31.10	1	1.2	1.2	Safe
43.02	18.67	40.71	13.79	1	0.5	0.5	Overload
52.49	10.29	51.64	9.41	1	0.3	0.3	Overload
52.49	36.76	42.25	31.15	1	0.67	0.67	Overload
52.78	26.82	47.10	23.82	1.45	0.5	0.5	Overload
52.78	43.32	38.61	35.99	1.45	0.78	0.54	Overload
61.36	34.38	50.63	34.66	1.16	0.4	0.34	Overload
61.10	41.52	45.73	40.52	1	0.5	0.5	Overload
61.06	43.15	44.53	41.78	1.45	0.65	0.45	Overload
61.21	56.05	34.17	50.78	1.45	0.8	0.55	Overload
72	54.33	41.97	58.5	1.16	0.58	0.5	Overload
72	19.94	67.68	24.56	1,5	0,16	0,11	Overload
72	25.27	65.1	30.76	1,16	0,16	0,14	Overload
72	33.01	60.37	39.24	1,45	0,33	0,23	Overload
29.43	22.87	27.11	11.45	0,48	1,3	2,72	Safe
39.19	64.81	16.66	35.47	1,87	2,3	1,23	Safe
48.35	42.12	35.85	32.44	1,47	0,7	0,7	Overload
66.24	46.93	45.21	48.41	1,47	0,5	0,5	Overload

IV. CONCLUSION

The design of a prototype load moment indicator based on a microcontroller that uses the nearest value search algorithm can provide information on the SWL value according to the closest value on the lifting load chart of the mobile crane accurately and in real-time. In addition, it can provide information as indicators when an overload occurs during the lifting load process. To determine the safe threshold, the load can be lifted using the load comparison value (the weight of the load lifted by the crane) and the SWL value. If the value of SF (safety factor) > 1.0, then is safe to lift. If the value of SF (safety factor) is 1.0, then it is overloaded.

ACKNOWLEDGMENT

Researchers would like to thank friends in the ITATS electrical department who have provided input and ITATS electrical engineering students who have helped manufacture this design of prototype LMI.

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