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by
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A Microprocessor-Based Crane Load State Monitoring System

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A MICROPROCESSOR-BASED LOAD STATE MONITORING SYSTEM

by Djamel BENAZZOUZ

To the memory of my father

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ABSTRACT

The objective of this research work is to develop a microprocessor-based system to monitor the load state and insure the safety of a mobile telescopic crane. The need for an automatic and intelligent system that determines the lifted load, in replacement to the existing design based on analog electronics, is to serve the National Crane Manufacturing Company ENMTP-CPG, Ain-Smara, Algeria. The conventional microprocessor-based systems use the searching technique (look-up tables) to read the allowed load stored in memory. The drawback of such technique is that it requires a large amount of memory space which would increase the searching time and the size of the hardware.

The solution adopted in the proposed design consists of developing an equation relating the specific working configurations to the allowed load. The relation is obtained through a numerical analysis method. This approach reduces greatly the memory space, since the microprocessor computes the allowed load from the coefficients proper to each configuration. This result was checked by the data of the 1040 crane model, which are in good agreement with the data provided by the manufacturer.

KEYWORDS: Microprocessor-based, Crane safe load, Monitoring, Crane load

PREFACE

The proposed research work deals with a microprocessor-based monitoring system that governs the load state and insure the safety of a mobile telescopic crane. This problem of monitoring the load state of a mobile telescopic crane was presented to INELEC by an Algerian Crane Factory at Ain-Smara (ENMTP-CPG) who are willing to support the project. The need for an automatic and intelligent system that monitor the crane load state is to replace the existing system based on analog electronics.

The design approach of such a system consists of three steps: the crane mechanical analysis, the crane mathematical modelling, and the hardware and software design.

The mechanical analysis step describes the mechanical behavior of the mobile telescopic crane under different stress conditions, and allows understanding the working environment this crane type is subject to.

Chapter 1 defines the crane type and gives a general crane description. It explains the causes of overturning and the need of designing such a system. At the end of this chapter, a brief discussion, concerning the major designers of such systems in the world, is given.

Chapter 2 describes the existing system design principle which is based on analog electronics, and states the major disadvantages, especially those related to the transducers step resolutions.

A brief discussion is given to describe the new system principle. It illustrates the position of the proposed transducers and shows the control display panel through which the operator can select the configuration and the data to be displayed. A listing of the system advantages is given at the end of this chapter.

Chapter 3 gives a detailed crane static analysis under various working conditions. These conditions are defined as the security level, the crane sitting mode, and the crane configurations. The determination of the allowed load is obtained through a numerical analysis, whereas, the lifted load determination is based on the proposed transducers.

The determination of the allowed load needs to understand perfectly the crane mechanical behavior under different stresses. The identification of these variance depends on special mechanical theory and rules, namely, those related to the norms DIN which are applied to this crane type. Because of these difficulties, chapter 4 explains how the mathematical model is used to approximate the allowed load. This was achieved by using numerical analysis methods that leads to the best optimum formula which governs crane operation, and gives the allowed load as a key parameter to the solution of the problem depending essentially on both the boom angle and length. Thus, the determination of the allowed load is by computation, unlike the conventional microprocessor-based crane load state monitoring systems, where the allowed load values are stored in memories. These values are read from memories according to the selected configuration.

Chapter 5 gives a detailed description on the control display panel and the function related to the different switches. Also it gives a system hardware description. This hardware was carefully designed in such a way to minimize the number of components used and hence the cost.

The system software is treated in chapter 6 where the software routines are explained. All the process of solving the various equations is fully described.

The last chapter, describes the difficulties in designing such a monitoring system and gives an approximated cost. It also suggests the possibility to standardize the system electronics by proposing a set of points for further work.

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

A crane is a mechanical system equipped in such a way that it can lift loads from one place and carries them to another, generally of different altitude. This load is usually unknown to the operator, and may put the crane in danger situation. The proposed research work is designed to prevent the crane from any danger by taking some actions such as stopping instantaneously the crane movement, displaying some useful information that help the operator in adjusting some parameters to insure a safe manoeuvrability. The operator is permanently informed on the load ratio through the panel display, placed on the board. This design approach is based on a mobile telescopic type which is manufacturer by an Algerian Crane Factory, the ENMTP-CPG at Ain-Smara, and the manufacturer requirements [1]. The model chosen is the "CPG 1040", which is shown in Fig.1.1, and described below. Therefore all the analysis and the derived formulas are only applied to this model.

1.1.1 Crane Description

The CPG 1040 is a mobile telescopic crane, which has a telescopic boom with a maximum length of 30 m. The boom is mounted on a rotating disc providing a slew through 360°, and has a maximum capacity of 40 tonnes. It is equipped as standard with four hydraulic four-point folding outriggers (called also stabilizer) independently controlled from the cab. The crane manoeuvre can be on outriggers or on wheels. It has a fully synchronized telescoping boom with a standard lattice extension which can be mounted or removed. The lifted range angle is 55° (minimum 10° and maximum 65°), so many of these parameters may change while the crane is operating. Therefore, some combinations of these parameters may not be allowed depending on the crane position and provoke a danger to the crane.

1.2 OVERTURNING FACTORS

A mobile telescopic crane is usually exposed to the risk of overturning due to overloading or/and improper positioning. This may result in a substantial damage to goods as well as to persons. The occurrence of overturning is due to the moment of the lifted load with respect to the rotation axis. This axis is normal to the vertical plane containing the boom. This moment depends on the weight of both the lifted load and the boom, the length and the angle of the boom, the swinging rate of the load, the sitting mode of the crane, the overbalancing reference axis, if the lifted load is over the side or the front of the crane as shown in Fig.1.2, and other specific parameters considered in the dynamics of the crane. Generally speaking this overturning moment is due to a lack of operator technical training and misjudgement of the lifted load.

A high degree of operators skill and performance is required to keep such an operation within a safe tolerance.

1.3 NEED FOR A MONITORING SYSTEM

The time response needed for controlling the above parameters requires a man-machine interface to assist the operator in monitoring the lifted load. The proposed system is designed to serve the purpose of this interface. However this control should not be left to the judgment of the operator because of the following reasons :

1- The evaluation of the crane operation needs instantaneous and cumbersome computations and precise measurements.

2- Generally, the lifted loads are unknown to the operator.

3- A human is subject to the concentration and the attention decay at any instant.

4- The experienced operator can do the job but with a margin of security and this results in loss in operation efficiency.

5- The operator attention is normally directed towards external manoeuvres rather than monitoring the load state on the crane.

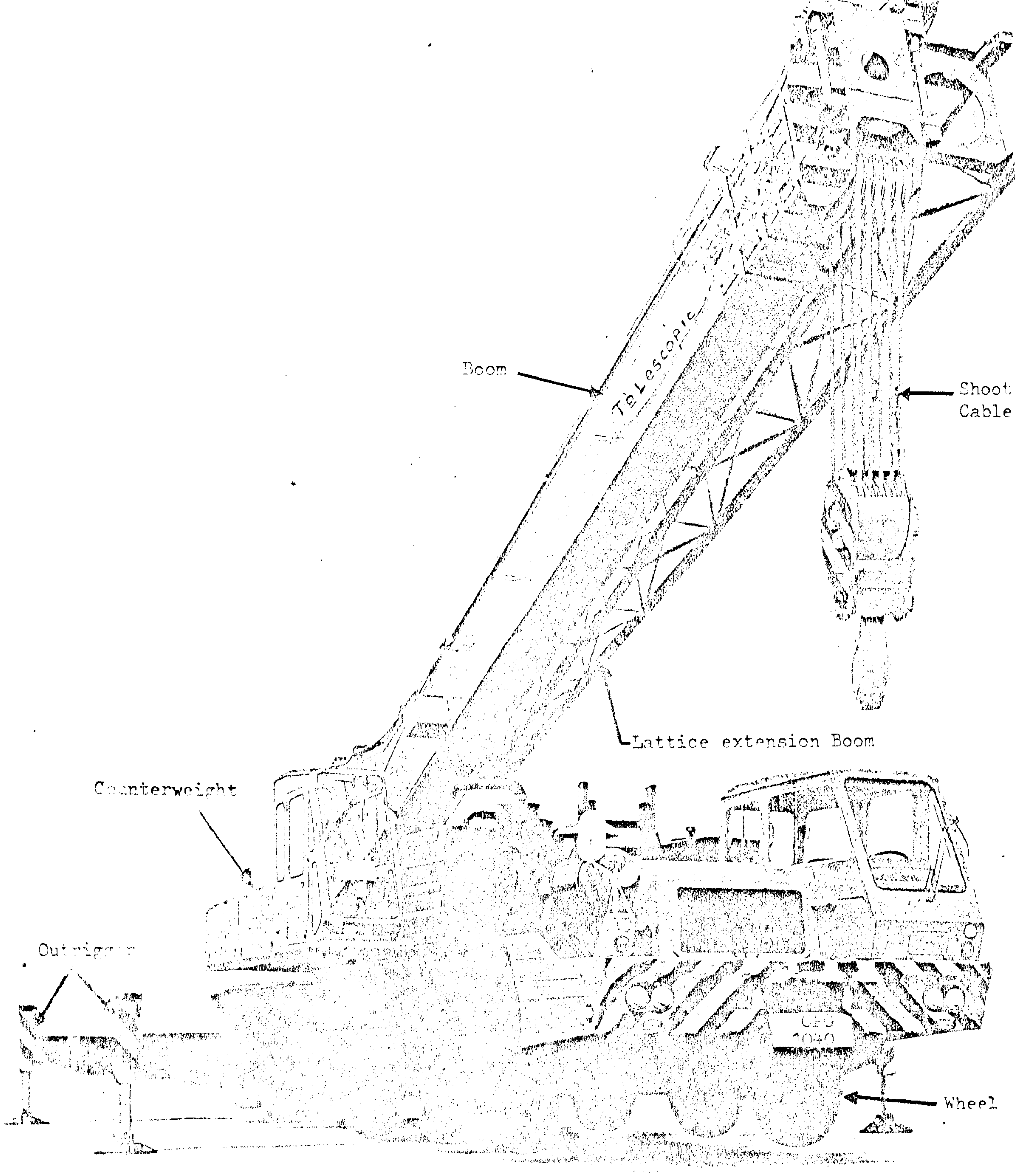
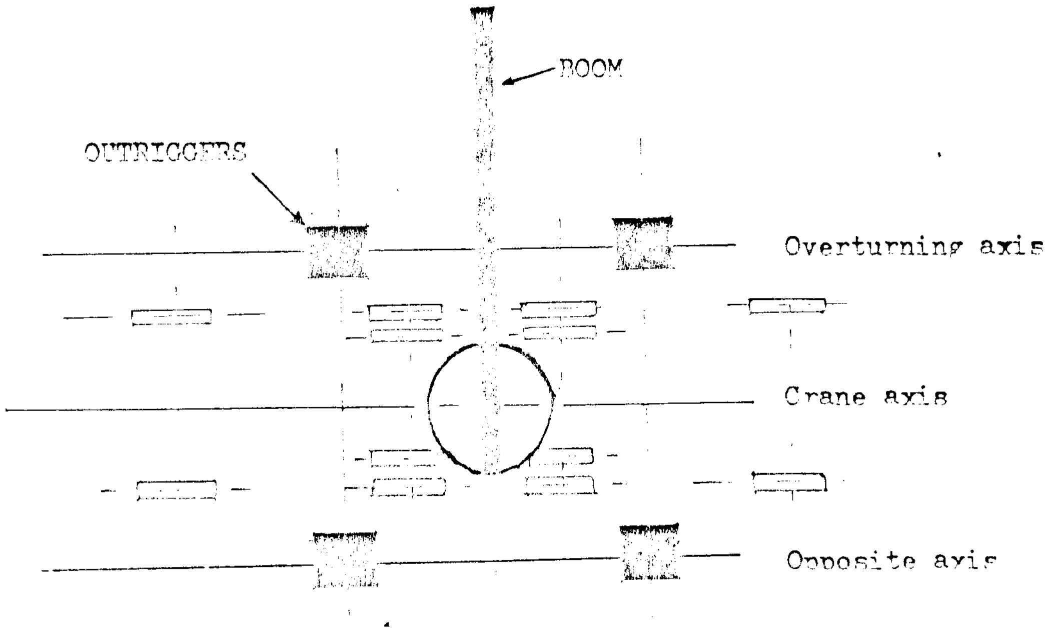


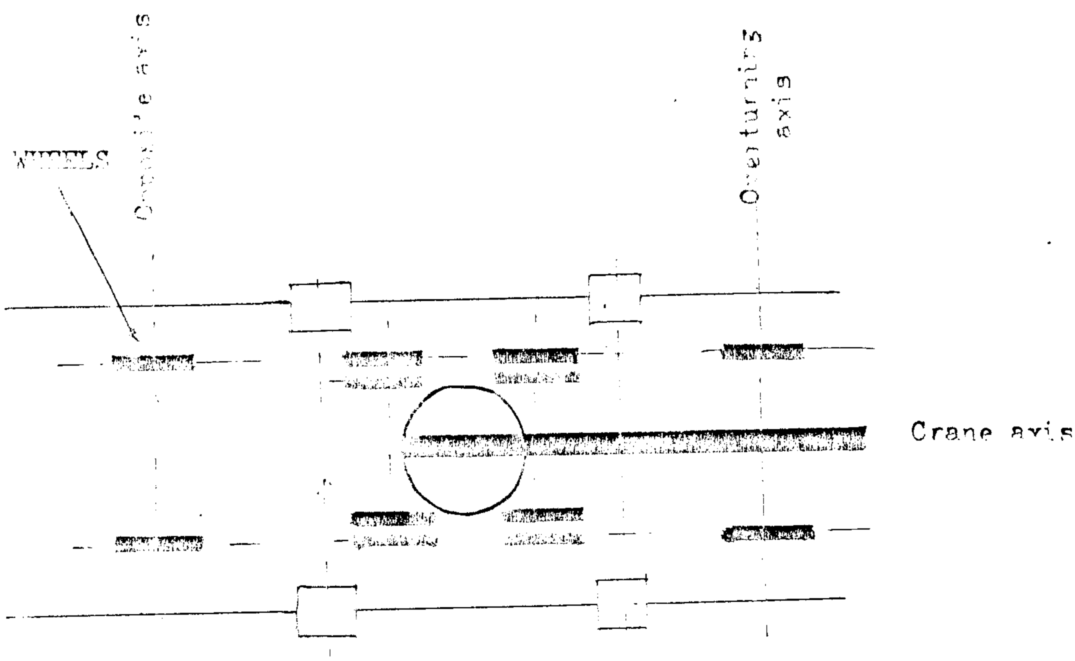
Fig1.1 CPG Crane Model 1040

On the other hand, an electronic system can always be designed to fulfil the above requirements and many others. The international conventions which require the presence of such systems on the crane go beyond that, and specify their characteristics such as, the ability to stop the crane movements, decide the maximum allowed load ratio, and calculate the allowed load percentage that can overturn the crane.

With the advent of microelectronics, it has become clear that a cost-effective and intelligent microprocessor-based monitoring system is feasible. Because MOS technology reduces the cost of hardware in computer systems by reducing the size of the packages and increasing the component density. This has opened the door to complex and important applications in various fields. The most important point about microprocessors is that, they have maximum flexibility for interfacing to a large variety of devices. Real-time applications need an interface to connect a physical system to a microprocessor. The interface consists of a minimum circuitry needed to condition the signals that originate in monitoring the crane to meet the input requirements of the microprocessor. It also treats microprocessor originated signals to provide what is needed by the operator. Such a system is generally called ' Load State Monitoring System '.



a. Outriggers mode (Boom perpendicular to the crane axis)



b. Wheels mode (Boom to the rear in the crane axis)

Fig.1.2 Sitting mode.and boom positions

The proposed system will assist the operator during crane manoeuvre and will take decisions on behalf of the operator in critical situations. Such a system can be governed by an unskilled person with little training and experience.

Note that, a safe system exits in the international market [2] with different technology. the most popular ones are given in the following section.

1.4 CRANE SAFE LOAD MANUFACTURERS

1) The EATON corporation has been a major producer of crane monitoring equipment in the United States. it is offering analog devices that gives a gross moment and percentages of operating limits. it uses a tensiometer to measure the lifted load.

2) LITTON Industries has developed a monitoring system based on a minicomputer and strain gauges to measure reaction forces at pivot points on the crane. and it is a very complex method and expensive.

3) KRUGER Company of West Germany is the current leader in mechanical monitors based on cams and gears. this system is moderately expensive and reliable system. but is not flexible from one crane to another.

4) PYE Limited in the U.K. through its ECKO subsidiary is the leading firm in the U.K. producing crane monitoring

devices based on electromechanical principles.

5) MARGANITE of U.K. is another leading company in Microprocessor-based crane load monitoring systems and produces different models but all uses the same measuring principles that is adopted in the proposed system. Prices of nearly all systems available, are very high compared to the size of the hardware required, software programming and effort put-in, and it ranges from 28000 FF to 50000 FF and this depends on number of units to be purchased.

CHAPTER 2

EXISTING AND PROPOSED SYSTEM DESCRIPTION

2.1 Existing system description.

2.1.1 Existing system.

2.1.2 System principle.

2.1.3 Disadvantages.

2.2 Proposed system description.

2.2.1 Advantages.

CHAPTER 2

2.1 EXISTING SYSTEM DESCRIPTION

2.1.1 Existing System

The existing system is based on an analog electronics, which occupies a large space. The design principle uses three type of transducers to acquire information. These transducers are:

- Angle transducer, placed in such a way to measure the angle with respect to the vertical. It is based on a rotative mechanism with 12 sector tracks, each sector represents 5 degrees, thus the full range measurement is 55 degrees. During crane manoeuvre, only one sector track can be selected, the first sector represents 10° and the last one 65°. Notice that, the measurement principle is based on discrete points with a step of 5 degrees, thus it has a poor resolution.

- Length transducer, is partitioned into three sections, and simulated by a serial switching mechanism made to activate each of the three micro-switches. The full length section is given by the three-section boom (when the three micro-switches are closed, 3/3), extend to 30 m and may be even more when the standard lattice extension boom is mounted. Alternatively the crane can be supplied with a two-section fully synchronized boom (2/3) with 23.9 m long, or a one-section boom (1/3) of 17.9 m length, or working just with the boom-base with 11.9 m long. The appropriate electronic card which contains a large amount of analog comparators is selected by the angle transducer sector, thus depending on the length used, a voltage is picked-up to be compared with the output of the force transducer at different working conditions. Notice that, this switching mechanism is based on a discrete measurement principle with a step of 6 m. All reference voltages need to be calibrated during installation process.

- Force transducer, is based on the bending force f at a point P placed on the boom. A strain gauge is used to measure the force f and attached to the side of the boom at the point P as shown in Fig.2.1a. The unique feature of this design is that the strain gauges bonded to the web of the 'I' section inner beam respond to shear force, not bending moments. This strain gauge is subject to variations in temperature. All voltages required are provided by 24v crane battery.

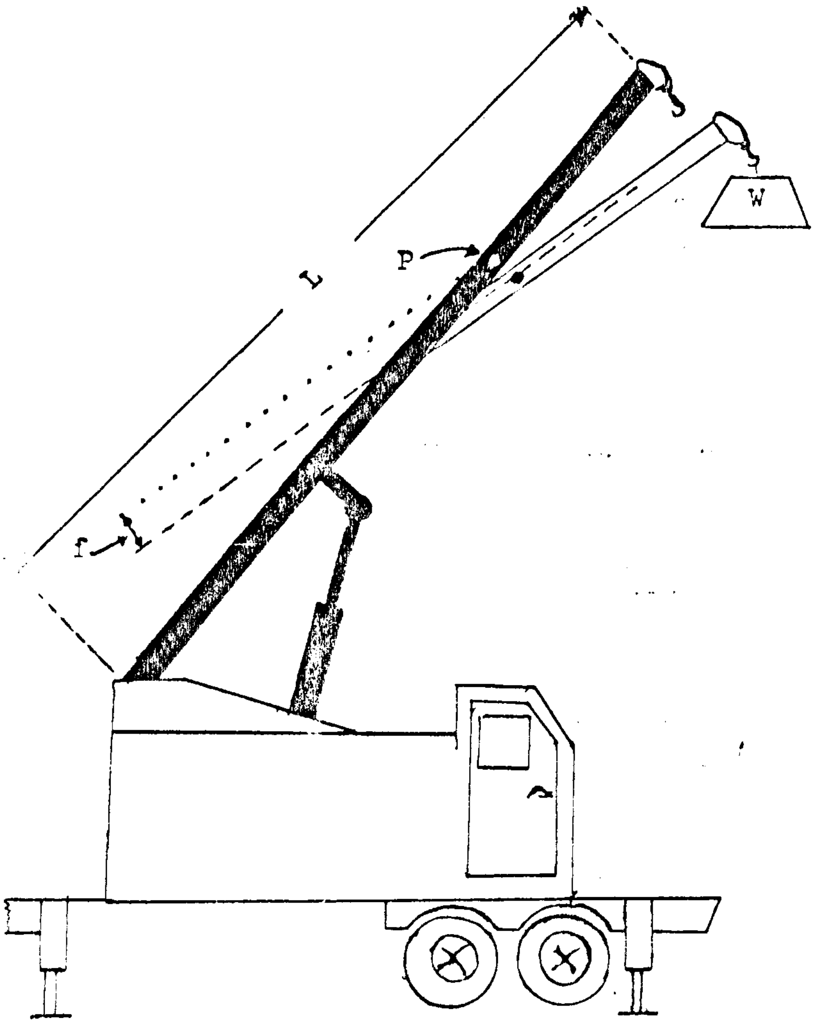
2.1.2 System Principle

The existing system block diagram is shown in Fig.2.1c. During calibration, the 3 length partitions and the 12 angle sectors are combined with the crane configuration to set up the maximum allowed load tables, which is illustrated in Fig.2.1b. These tables are stored in memory. During normal operation, the selected configuration (using the program preselector), and the length are coupled to address the memory. These represent 5 stored angle points whose values are applied to the angle potentiometer. Depending on the actual angle a voltage is picked up and driven to the comparator. this voltage represents the maximum allowed load. The force transducer is used to measure the lifted load. Comparison is made between the lifted and allowed load, then decision is taken, either to allow lifting, or to stop the crane movement by indicating the corresponding fault through relay, and lamps on the display console unit.

At a load ratio greater than 100%, the overload state is declared by stopping the crane movement, whereas between 85% and 100% a warning state is declared, and finally below 85% indicating the safe working conditions. These states are indicated through the analog display.

However, such a system represents some disadvantages which are described below and because of these reasons and others, the manufacturer have been expressed the need of a sophisticated design based on a microprocessor to monitor the lifted load and also providing a new display console that may help the operator in adjusting some parameters to insure the crane manoeuvre.

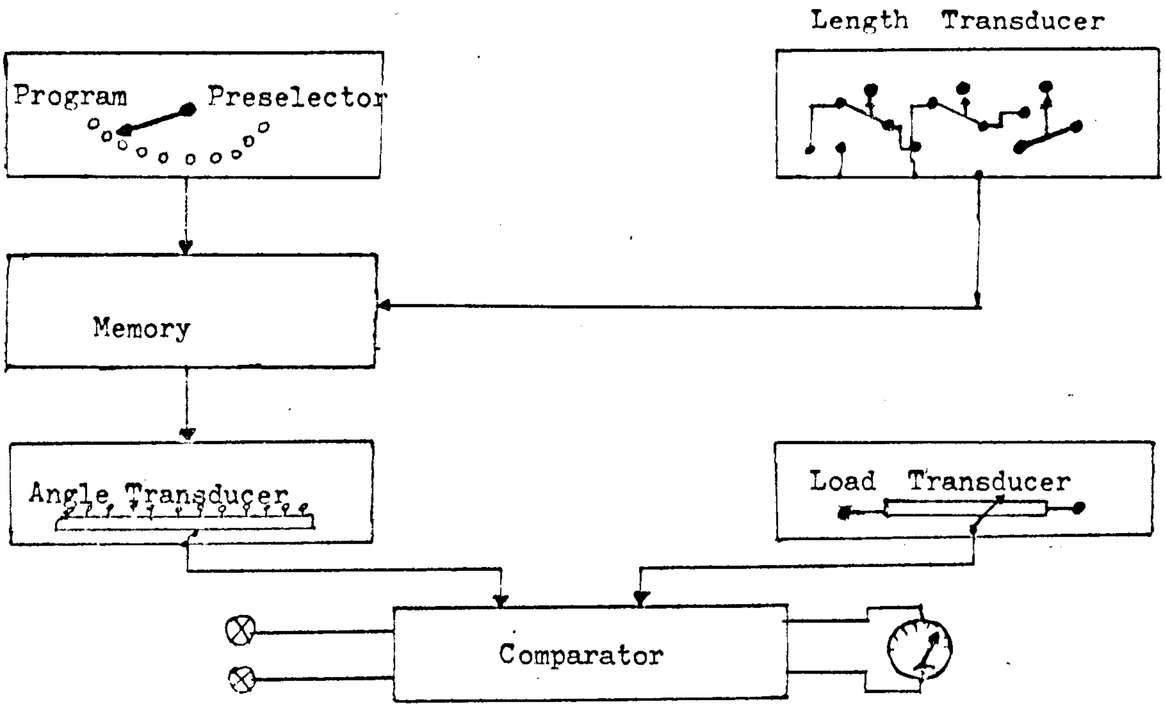
Fig.2.1 Existing system principle



a. Bending

Angle(°)	Volts	Conditions
15 °	2.80	Program N° 6
20 °	1.95	
25 °	1.85	Not Stabilised
35 °	1.70	(to rear)
70 °	1.30	5.5 t T 1/3

b. Load table



c. System block diagram

2.1.3 Disadvantages

- A big analog circuitry occupying a large space, which increase the risk of fault, and need more maintenance.

- Limited precision, due to the type of transducers.

- Low system efficiency, due to large length and angle resolution.

- Large angle and length measuring steps that may lead to a non-indicated hazardous conditions.

- Less informative.

- Requires manual and point-to-point time consuming calibration.

2.2 PROPOSED SYSTEM DESCRIPTION

The proposed system is based on the evolution of microelectronics technology and its great revelation, the microprocessor.

This system uses three proposed type of transducers as shown in Fig.2.1b,a :

- Angle transducer (linear potentiometer 1% error).
- Length transducer (linear potentiometer 1% error).
- Pressure transducer (range of 500 bars).

Three approaches have been developed to monitor the lifted load. First, the determination of the lifted load is based on the crane mechanical analysis using the proposed transducers. Second, the evaluation of the allowed load is obtained through a relation, without passing through the complex mechanics theory, this evaluation is defined as the crane mathematical model. Third, the boom moment is computed using a linear relation, instead of using decomposition theorem. These approaches are detailed in the next two chapters.

The system description diagram is shown in Fig.2.2, which illustrates the crane type, and the display console unit. On the display console unit we find some commutators from S_1 to S_7, made available to the operator to set the crane working configuration as well as the data to be displayed. This is used so, to inform the operator on different parameter to perform a good functioning.

2.2.1 Advantages

- Real time monitoring system.
- Fast respond time.
- Precision depends directly on the transducer rather than on the microprocessor system.
- Continuous step of length, angle and pressure.
- Small size of circuitry.
- Software programming offers a great flexibility in the system modification.
- Possible diagnosis software facilities system maintenance.

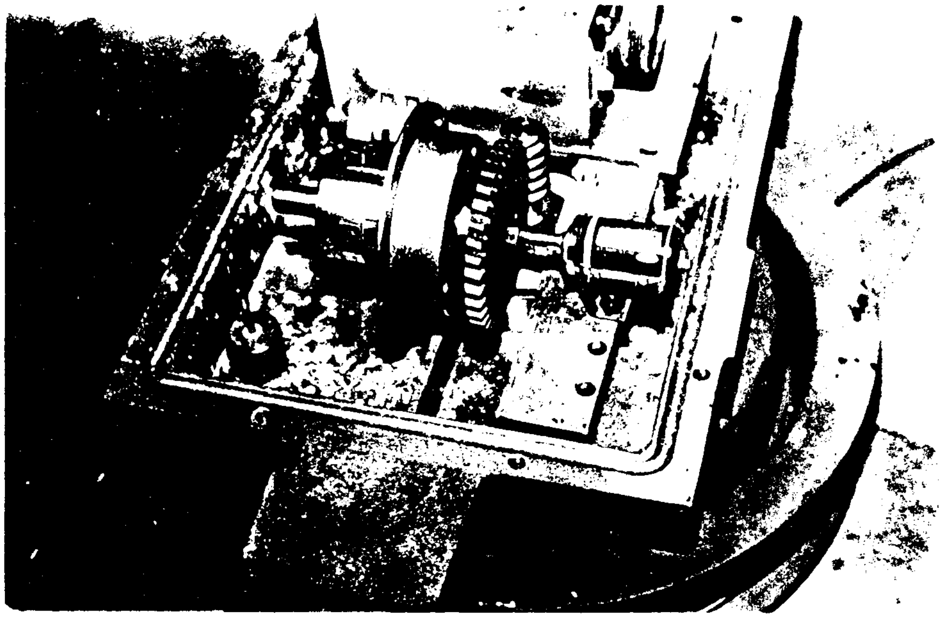


Fig.2.1a Length transducer

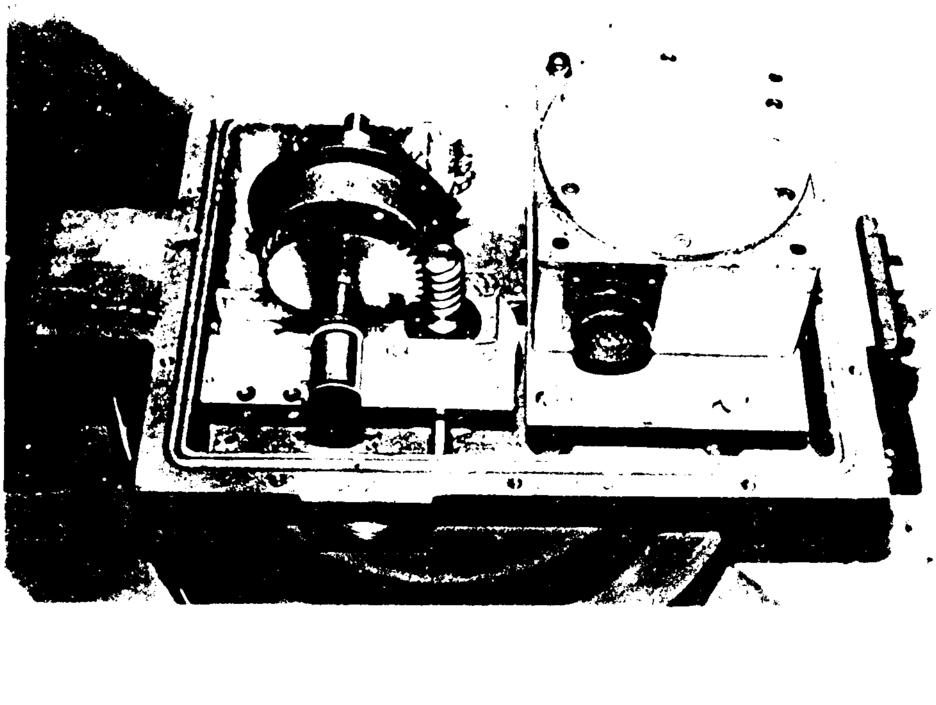


Fig.2.1b Angle transducer (on the right)

- The design can be implemented on a wide versatility of crane type without any modification in the hardware. The particular design specification for each crane are considered in software routines.

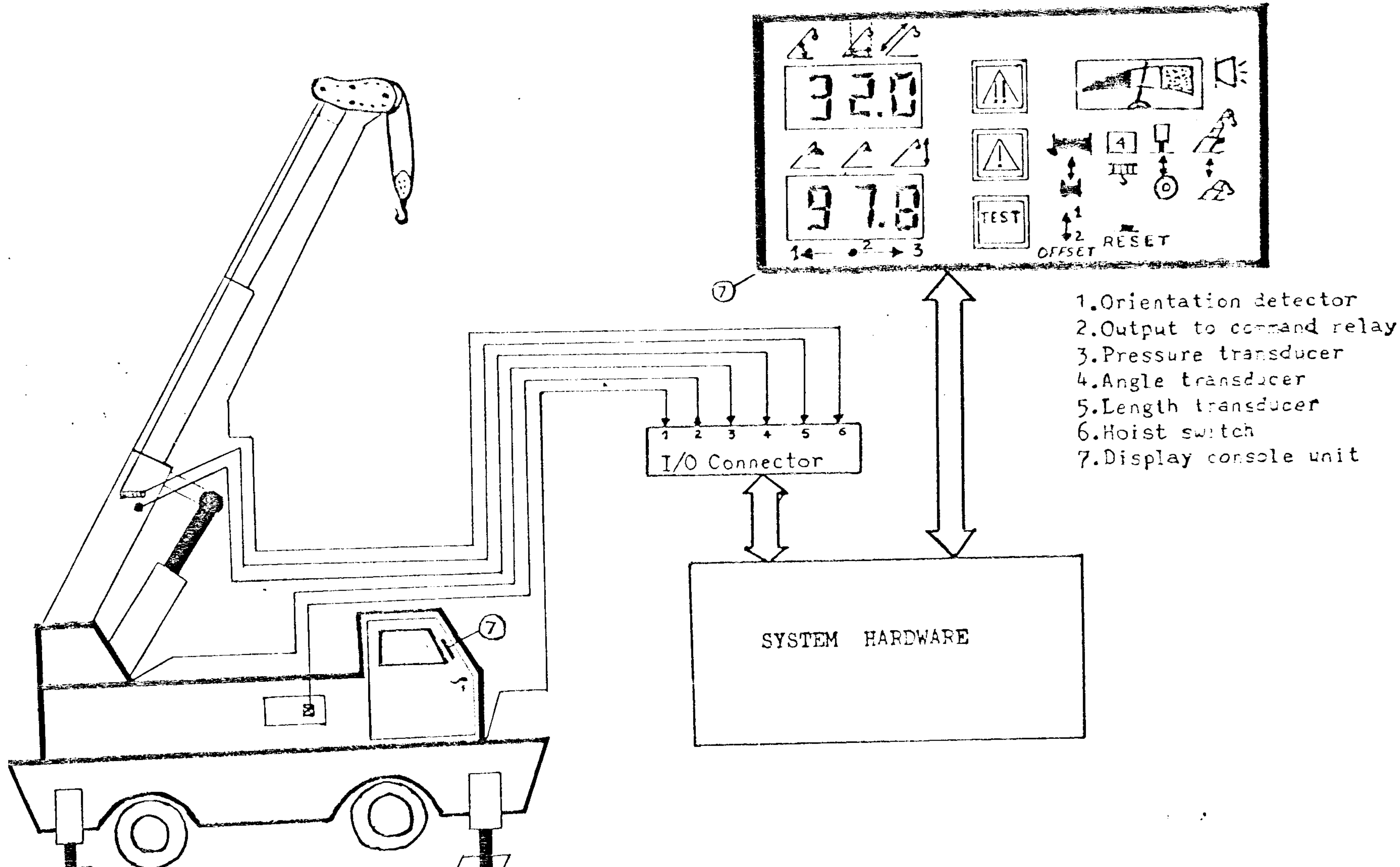


Fig.2.2 SYSTEM DESCRIPTION

CHAPTER 3

CRANE STATIC ANALYSIS

CHAPTER 3

3.1 CRANE STATIC ANALYSIS

Based on the three proposed transducers, the international standard norms [3], and the crane model particularity, a crane mechanical analysis is studied and formulas of different parameters were derived. They are given in a compact form as function of the measured variables. These variables are defined as the outputs of the three transducers, where α, L, and P_R expresses respectively the boom angle, the boom length, and the pressure. Other parameters are also considered, which are *constants* and known as the data crane personality.

3.1.1 Security Level

According to the International standard norms (norm DIN), which defines many mechanical rules namely the load swinging rate, the wind force, the safety factor, the crane material constraint, and many others. The most important is the norm DIN 15019, which specifies that, only 75% of the maximum allowed load is to be lifted. This is due to the fact that many parameters are uncontrollable, and may change under the dynamic behavior of the crane.

3.1.2 Sitting Mode

The sitting mode is one of the most important parameter which defines the allowed load. The CPG 1040 offers two sitting modes which are:

a) *Wheels mode*: The crane can operate on its wheels, where the boom has to be oriented to the rear, because it is the only possibility to have a good stability which correspond to a maximum load that can be lifted. Note that, the rotational axis is in the middle of the crane chassis, which is defined as the virtual ground. The boom orientation is shown in Fig.1.2b. A magnetic switch is used to detect this orientation, and it is placed on the rotating disc upon which the boom is mounted. The maximum boom length is 17.9m.

b) *Outriggers mode*: The crane is on its outriggers having a boom freedom of 360°, therefore the boom can swap over all the crane axis. Because of this freedom, the crane analysis considers two overbalancing axis references. The first, is defined as, when the boom orientation is in front of the crane, the second, is defined as, when the boom is over the crane side. Since that two overbalancing axis are possible, it will automatically lead to two free ranges, where the free range is defined as the distance from the lifted load (projection to ground) to the overbalancing axis reference. F_{Y1} represents the free range when the boom is parallel to the crane axis, and F_{Y2} when the boom is perpendicular to the crane axis, as shown in Fig.1.2a. The use of outriggers offer more stability to the crane, because it has an appropriate sitting on the ground. The maximum boom length is 30m, and the orientation switch should be disabled.

3.2 ALLOWED LOAD DETERMINATION

Based on the crane mechanical analysis, the maximum allowed load is given by:

$$P_K = \frac{M_S}{F_Y} \qquad (1.1)$$

Where : M_S is the overbalancing moment

F_Y is the free range

P_K is the maximum overbalancing load.

Referring to Fig.3.1, which shows the static equilibrium, and the distributed weights overall the crane parts. The overbalancing moment is computed from mechanical data, such as those related to counterweight, chassis weight, rotating disc weight and other weights as specified in Fig.3.1. These data are provided by the manufacturer and used to compute M_S.

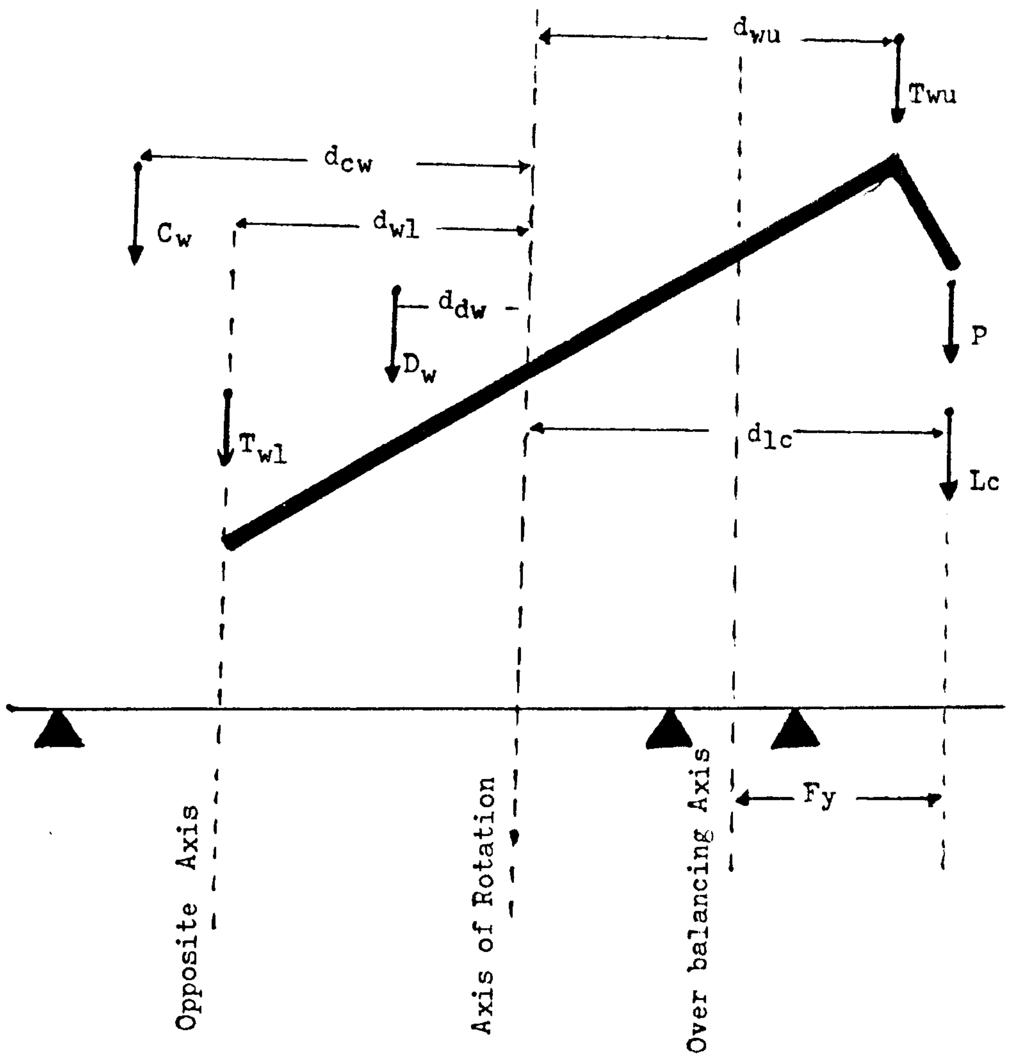


Fig.3.1 Overbalancing moment

Cw : Counter Weight
d_{cw} :distance between Cw and axis of rotation
T_{wl} :telescope weight acts at the lower end
d_{wl} :distance between T_{wl} and axis of rotation
D_w ::Turret (rotating disc) weight
dd_w :distance between Dw and axis of rotation
T_{wu} :telescope weight acts at the upper end
d_{wu} ;distance between T_{wu} and axis of rotation (may +ive or -ive)
Lc :lift cable weight
d_{lc} :distance between Lc and axis of rotation (may +ive or -ive)
Chw :chassis weight
d_{chw}:centre of chassis and axis of rotation

$$Ms = Chw.d_{chw} + Cw.d_{cw} + Twl.d_{wl} + Dw.d_{dw} + T_{wu}.d_{wu} + Lc.d_{lc}$$

The evaluation of the overbalancing load needs the identification of the free range. This free range depends on the overbalancing axis reference and the load axis projected to the platform. Since the crane can have two overbalancing axis as mentioned previously, the considered reference will depend on the load axis and the boom orientation. The boom orientation can change continuously while the operator is manoeuvring. However, trying to identify the free range, and the overbalancing load need a complex mechanical analysis, and because of this complexity, the manufacturer provides these loads in tabulated form referred to as '*load tables*', which are given in Appendix A, and specify under what configuration (different crane positioning) these data are valid. A proposed solution has been given, which leads to a good results as those given by the manufacturer.

3.2.1 Proposed Solution

The dynamic analysis of a crane is required to determine the allowed load to be lifted. Because of the complexity of the equations governing the crane behavior under dynamic conditions, the manufacturer provides a set of Load Tables. These data are used to develop a mathematical model which gives the allowed load through a numerical analysis method. This model is implemented by software in the system memory and can be easily used by an electronics engineer with limited knowledge in mechanical design. This mathematical model is described in the next chapter.

3.3 LIFTED LOAD DETERMINATION

The lifted load is the load hooked by the crane and not necessarily represents the overbalancing load. If the lifted load exceeds the allowed load, it can then be called as the overbalancing load. Hence, as the crane should always operate at only 75% of its overbalancing load, the lifted load can be determined by analysing the static state of forces acting on the crane boom, and considering the crane chassis as a platform on virtual ground. The force and the data needed for determining this load are given by the output transducers.

The advantage of using these transducers is that, it gives a continuous signal to the system, and the step can be decided by software.

Referring to Fig.3.2 which shows the different forces exerted on the crane.

at equilibrium:

$$\sum \vec{M}_{/0} = \vec{M}_{F_R} + \vec{M}_{P} + \vec{M}_{T} + \vec{M}_{PC} = 0 \qquad (1.2)$$

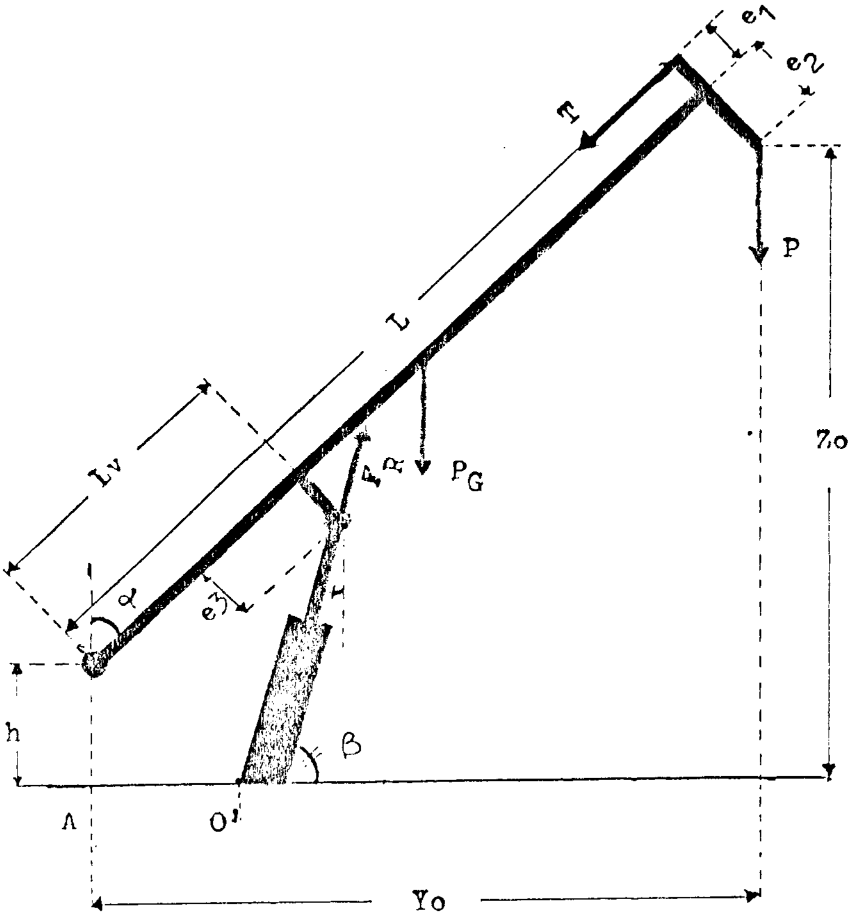


Fig. 3.2 Load expression

Where 'O' is the crane rotational disc axis. The parallel outrigger boxes are welded integral to the frame, giving the crane a virtually square blocking base. This reference axis is considered to be the middle of the square blocking base for both sitting modes. The determination of each term of Eq.1.2 is given below:

a/ Lifted Load Moment M_P

Referring to Fig.3.2, the lifted load moment is given by:

$$M_P = PY_0 \tag{1.3}$$

where

$$Y_0 = L\sin\alpha + e_2\cos\alpha \tag{1.3a}$$

b/ Tension Cable Moment M_T

Referring again to Fig.3.2, the tension cable moment is as follows:

$$M_T = Te_1 \tag{1.4}$$

where

$$T = \frac{P}{N} \quad (N = number \;\; of \;\; shoots) \tag{1.4a}$$

c/ Boom Moment M_{PC}

Since the gravitational centre of the boom changes depending on its length, and the distribution weight of the boom is non-uniform along its length, the mechanical engineers use the decomposition theorem to find the boom moment. This process needs a lot of computations, and hence more consuming time of the processor. The approach given in the proposed design is to look for a relation between the boom moment and its length. In fact there exist a linear relationship between them. This relation is demonstrated referring to Fig.3.3, as follows:

The boom completely IN is shown in Fig.3.3a, its moment is:

$$M_{\epsilon} = A_0P_0 + A_1P_1 + A_2P_2$$

The boom completely OUT is shown in Fig.3.3b, its moment is:

$$M_{out} = A_0P_0 + (A_1 + c)P_1 + (A_2 + 2c)P_2$$

The distance (2c) is fix with respect to the distance (c) because the hydraulic system synchronizes the three sections. As an example, if the second boom section moves out by a distance c, the third section will be automatically at 2c.

$$P_1 + 2P_2 = \frac{M_{\epsilon} - M_{out}}{c} = 2\frac{M_{\epsilon} - M_{out}}{L_{max} - L_{min}}$$

at any distance x, the moment will be:

$$M_X = M_{\epsilon} + (P_1 + 2P_2)X$$

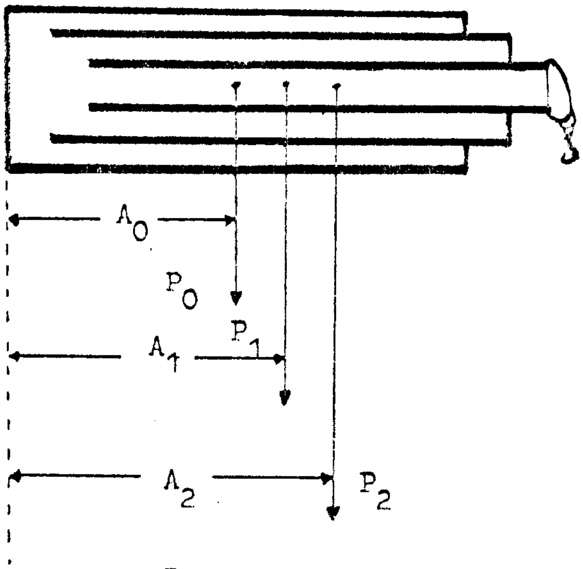
$$M_X = M_{\epsilon} + 2\frac{M_{out} - M_{\epsilon}}{L_{max} - L_{min}}X$$

In the general form :

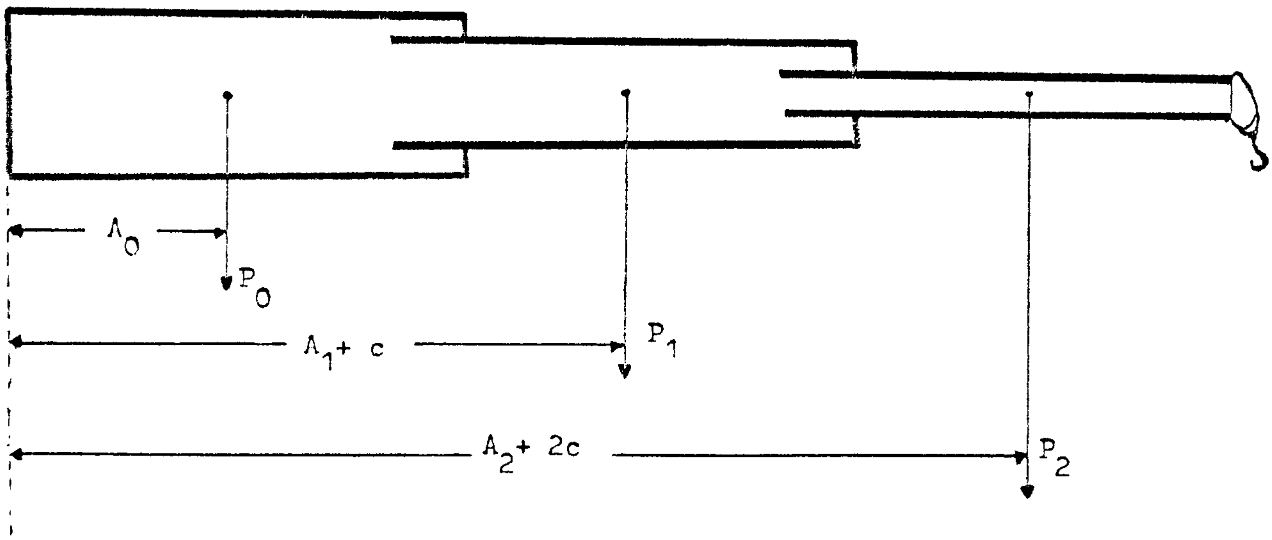
$$M_X = aL + M_{\epsilon} \qquad (1.5)$$

where

$$a = 2\frac{M_{out} - M_{\epsilon}}{L_{max} - L_{min}} \qquad (1.5a)$$



a. Boom completly IN



b. Boom completly OUT

Fig.3.3 Boom Moment

As the boom moves upwards to form angle α , a correction factor $\sin\alpha$ is to be added in Eq.1.5.

d/ Hydraulic Jack Moment M_{FR}

Referring to Fig.3.4a, the hydraulic jack moment is given by:

$$M_{FR} = F_R d \qquad (1.6)$$

The determination of the distance d is demonstrated as follows:

$$d = OC - M'C \qquad \tan\beta = \frac{AC}{h} \qquad AC = AO' + O'C$$

$$OC = \frac{h}{\cos\beta} \qquad CM' = CO'\sin\beta$$

$$CO' = AC - AO' = h\tan\beta - AO'$$

$$d = \frac{h}{\cos\beta} - (h\tan\beta - AO')\sin\beta = \frac{h}{\cos\beta} - \frac{h\sin^2\beta}{\cos\beta} + AO'\sin\beta$$

therefore

$$d = h\cos\beta + AO'\sin\beta \qquad (1.6a)$$

replacing each Moment's term in Eq.1.1, we end up with the following equation:

$$P = \frac{F_R(h\cos\beta + AO'\sin\beta) - M_X\sin\alpha}{\psi\left(L\sin\alpha + e_2\cos\alpha - \frac{e_1}{N}\right)} \qquad (1.7)$$

since

$$\beta = 90 - \alpha'$$

and we know that:

$$\cos\beta = \cos\left(\frac{\pi}{2} - \alpha'\right) = \sin\alpha'$$

therefore, the final lifted load expression is given by:

$$M = \frac{F_R(h\sin\alpha' + AO'\cos\alpha') - M_X\sin\alpha}{\psi g\left(L\sin\alpha - e_2\cos\alpha - \frac{e_1}{N}\right)} \tag{1.8}$$

where the three variables are α, L, P_R, with P_R being the output of the pressure transducer. The remaining terms are constant, and constitute the data crane personality, ψ is the safety coefficient which takes the value of 1.2; and if S is the piston area of the hydraulic jack, $F_R = P_R.S$. Note that, P=M.g , g is the gravitational acceleration.

These variables are fed into the microprocessor through three transducers located at selected points on the crane (see Fig.2.2). Note that, the determination of α' is based on the illustration given Fig.3.4b, and the equation is as follows:

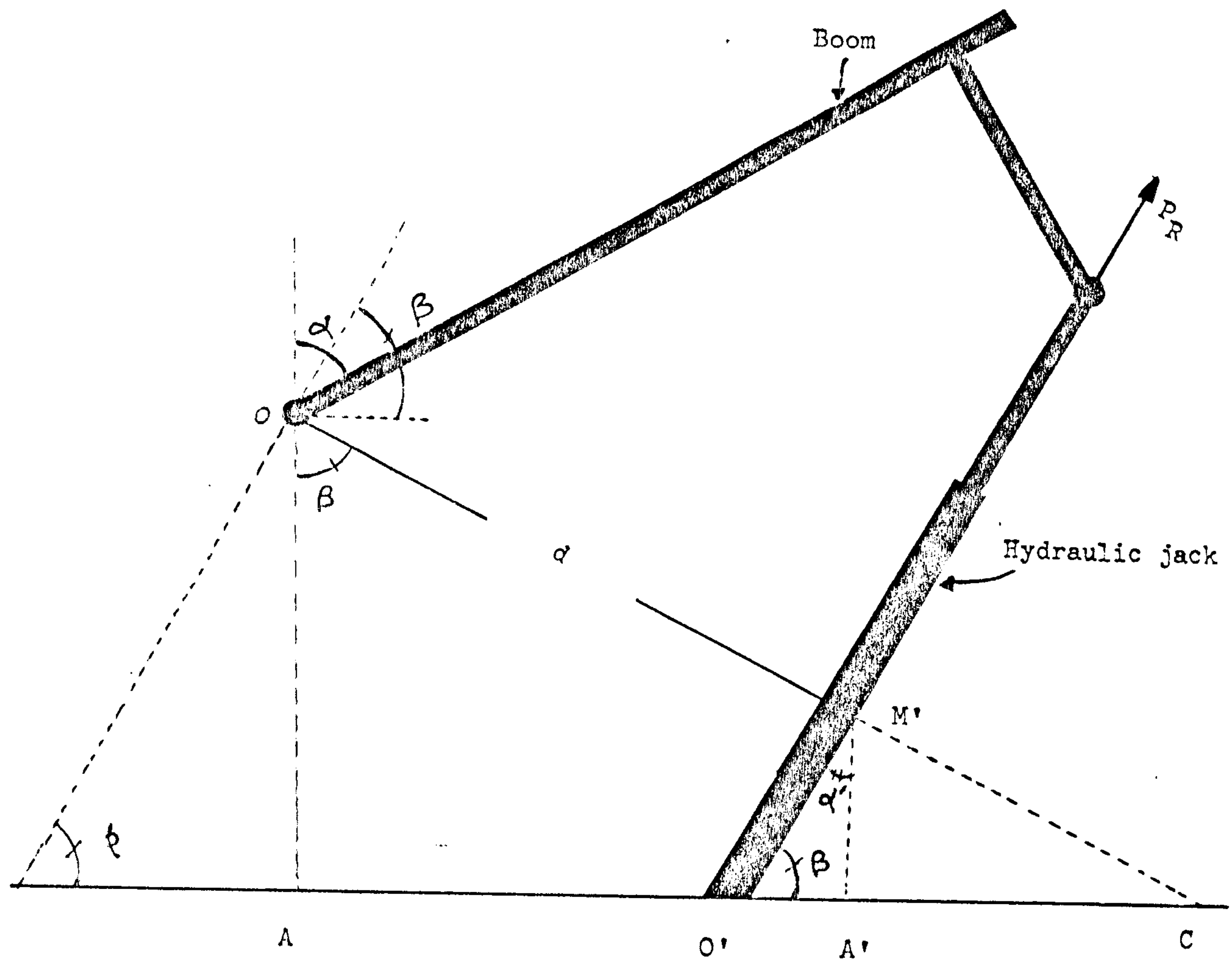
$$\tan\alpha' = \frac{L_v\sin\alpha + e_3\cos\alpha - O'A}{L_v\cos\alpha - e_3\sin\alpha + h} \tag{1.8a}$$

The other useful quantities needed by the operator to be displayed on the

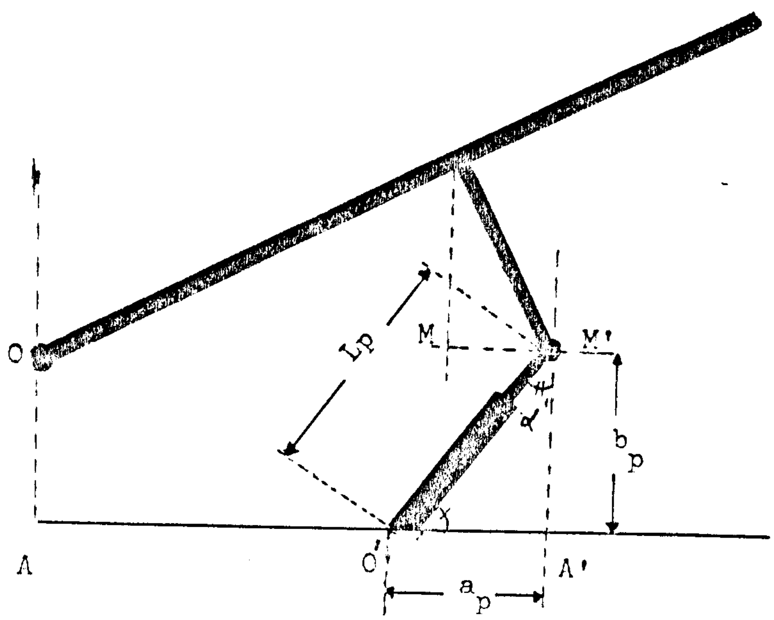
console unit are the height, Zo, and the free range, Yo, respectively given by:

$$Z_0 = L\cos\alpha - e_2\sin\alpha + h \tag{1.9}$$

$$Y_0 = L\sin\alpha + e_2\cos\alpha - O'A \tag{1.10}$$



a. Hydraulic jack moment



b. Determination of α'

Fig.3.4 Hydraulic jack moment and α' determination

CHAPTER 4

CRANE MATHEMATICAL MODEL

CHAPTER 4

4.1 CRANE MATHEMATICAL MODEL

Based on the load tables given in Appendix A, a mathematical model was developed to determine the allowed load through a numerical analysis method. This approach can be applied to any given mobile telescopic crane. The derived coefficients are proper to the model 1040, and they are known as the data crane personality and given at the end of this chapter. Before developing this model, it is necessary to understand what is meant by configuration, and what are the allowed ones.

4.1.1 Crane Configuration

The crane model 1040 offers four possible configurations, each of which is defined by a set of load tables. These configurations are characterized by a number of parameters. First, the setting mode which determines whether the crane is on outriggers or on wheels. Second, the counterweight which can be either 5.5 or 2.0 tonnes. Third, the lattice extension boom which can be mounted or removed (used to extend the boom length), and finally the number of shoots making up the cable. The four allowed configurations are:

- 5.5t counterweight using outriggers (4 tables).
- 5.5t counterweight using wheels (2 tables).
- 2.0t counterweight using outriggers (4 tables).

- 2.0t counterweight using wheels (2 tables).

In order to approximate these load tables, data representing the allowed load at fixed length were plotted acquired different angles and graphs were examined. For the purpose of this demonstration, it is considered that the crane is mounted on outriggers with a counterweight of 5.5 tonnes, and without lattice extension boom. This configuration is defined by the curves shown in Fig.4.1. These data are given in the first four tables in Appendix A.

First table, is defined for L=11.9m

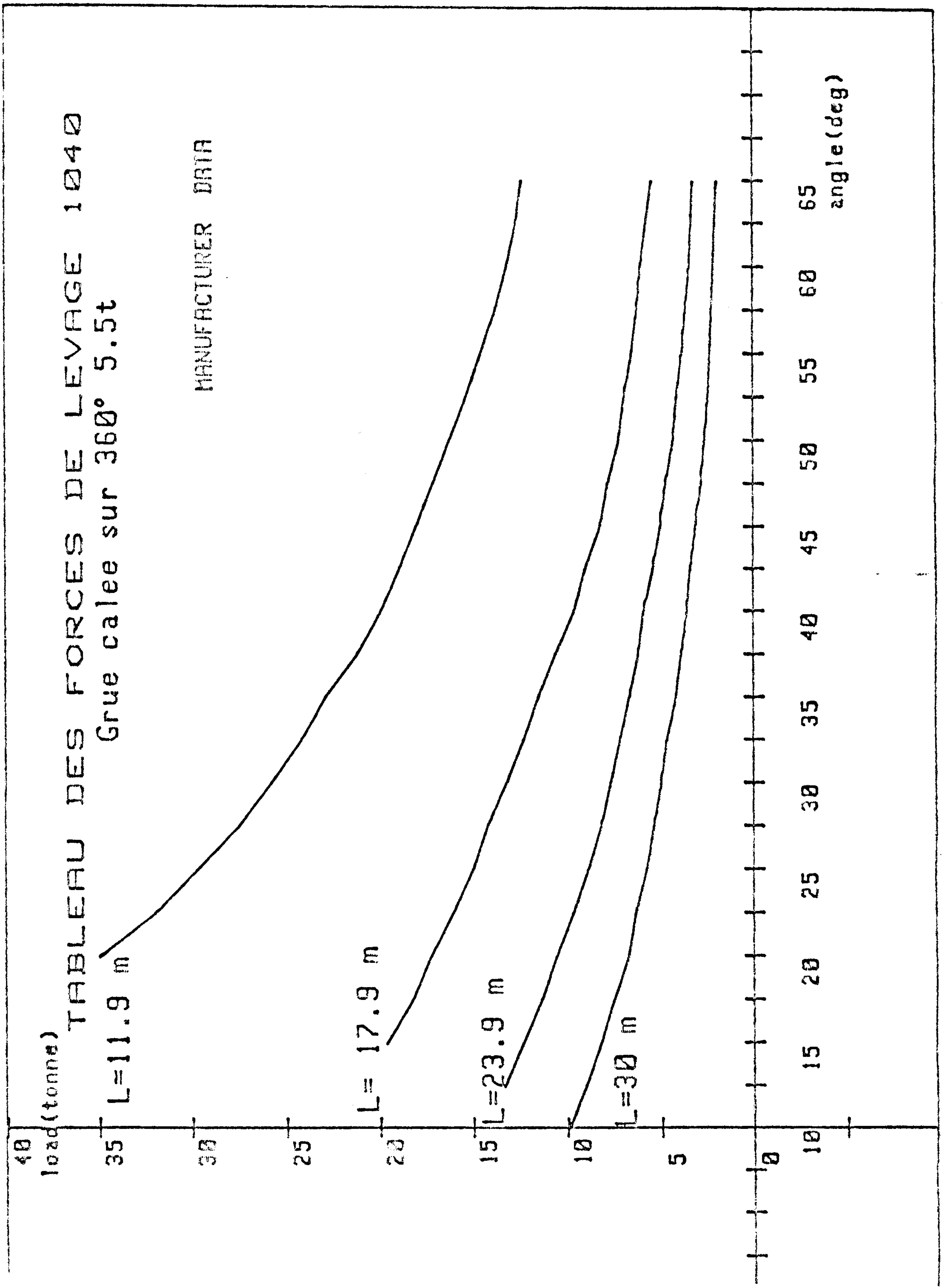
Second table, is defined for L=17.9m

Third table, is defined for L=23.9m

Fourth table, is defined for L=30.0m

Notice that, these curves are smooth, regular, but there is no linear interpolation between two different length steps, which means that, the curve for L=17.9m is not in the middle between L=11.9m and L=23.9m. The Least Square method is adopted to approximate these curves. This method is defined as 'find the values of the constants in the chosen equation that minimize the sum of the squared deviations of the observed values from those predicted by the equation'. The form of the general relation, is of the polynomial form which is among the easiest empirical equation to fit. For more details about the Least Square method known also as the Multi-Nonlinear Regression method because for the study case

Fig.4.1 Manufacturer data



the allowed load depends on two variables, and it is given in reference [4]. This method is applied to the third order for each curve, thus, the obtained equation is of the form of:

$$F_N(\alpha) = K_0 + K_1\alpha + K_2\alpha^2 + K_3\alpha^3 \tag{4.1}$$

This function represents the allowed load as function of the angle (α), where L is a constant parameter. The subset N, and the coefficients K stand only for designation. If L=11.9m, then N=0 and K=A. The same attribution will be for the second curve, when L=17.9m, then N=1 and K=B and so on. Thus, the four equations of the first four curves are:

$$F_0(\alpha) = A_0 + A_1\alpha + A_2\alpha^2 + A_3\alpha^3 \tag{4.1a}$$

$$F_1(\alpha) = B_0 + B_1\alpha + B_2\alpha^2 + B_3\alpha^3 \tag{4.1b}$$

$$F_2(\alpha) = C_0 + C_1\alpha + C_2\alpha^2 + C_3\alpha^3 \tag{4.1c}$$

$$F_3(\alpha) = D_0 + D_1\alpha + D_2\alpha^2 + D_3\alpha^3 \tag{4.1d}$$

Therefore, for the considered configuration sixteen coefficients have been derived. Since, it is possible to approximate these data as function of the angle (α), thus, the same approach can also be used to look for the [illegible] load as a function of the length (L), then, the [illegible] equations are of the form:

$$F_N(L) = A + BL_N + CL_N^2 + DL_N^3 \qquad ([illegible])$$

Therefore, it is possible to equate these functions [illegible] they represents the same load tables.

$$F_N(L) = F_N(\alpha)$$

Notice that, each of the coefficient A, B, C, and D of Eq.4.2 are function of the angle (α). If the [illegible] technique is used to look for these coefficients, the [illegible] derived coefficients of the allowed load as function of [illegible] defines the MAT (A), the MAT (L) defines the known [illegible] the MAT (α) defines the variable α, and finally the (COEF) defines the unknown coefficients.

$$\text{MAT A} = \begin{bmatrix} A_0 & A_1 & A_2 & A_3 \\ B_0 & B_1 & B_2 & B_3 \\ C_0 & C_1 & C_2 & C_3 \\ D_0 & D_1 & D_2 & D_3 \end{bmatrix} \qquad \text{MAT L} = \begin{bmatrix} 1 & 11.9 & 11.9^2 & 11.9^3 \\ 1 & 17.9 & 17.9^2 & 17.9^3 \\ 1 & 23.9 & 23.9^2 & 23.9^3 \\ 1 & 30.0 & 30.0^2 & 30.0^3 \end{bmatrix}$$

$$\text{MAT } \alpha = \begin{bmatrix} 1 \\ \alpha \\ \alpha^2 \\ \alpha^3 \end{bmatrix} \qquad \text{MAT COEF} = \begin{bmatrix} A \\ B \\ C \\ D \end{bmatrix}$$

mathematical [illegible]

MAT (A) x MAT (α) = MAT (L) x MAT (COEF)

MAT (COEF) = MAT INV (L) x MAT (A) x MAT (α)

After determining the MAT (COEF), the allowed load formula as function of both the angle and the length is obtained and written as follows:

$$A_L(\alpha, L) = A + BL + CL^2 + DL^3 \qquad (4.4)$$

where these coefficients are the form of :

$$A = A_0 + A_1\alpha + A_2\alpha^2 + A_3\alpha^3 \qquad (4.4a)$$

$$B = B_0 + B_1\alpha + B_2\alpha^2 + B_3\alpha^3 \qquad (4.4b)$$

$$C = C_0 + C_1\alpha + C_2\alpha^2 + C_3\alpha^3 \qquad (4.4c)$$

$$D = D_0 + D_1\alpha + D_2\alpha^2 + D_3\alpha^3 \qquad (4.4d)$$

Replacing the obtained coefficients in Eq.4.4, the curves of the study case were plotted and shown in Fig.4.2. Based on the precision requirement of the system, the results of the computation are in good agreement with the data provided by the manufacturer. The validity of the present procedure is verified by calculating intermediate curves which, indeed, exhibit their nonlinear distribution on the graph with varying L as shown in Fig.4.3. Notice that the numerical method and the proposed one leads to the same results.

Fig.4.2 Approximated data

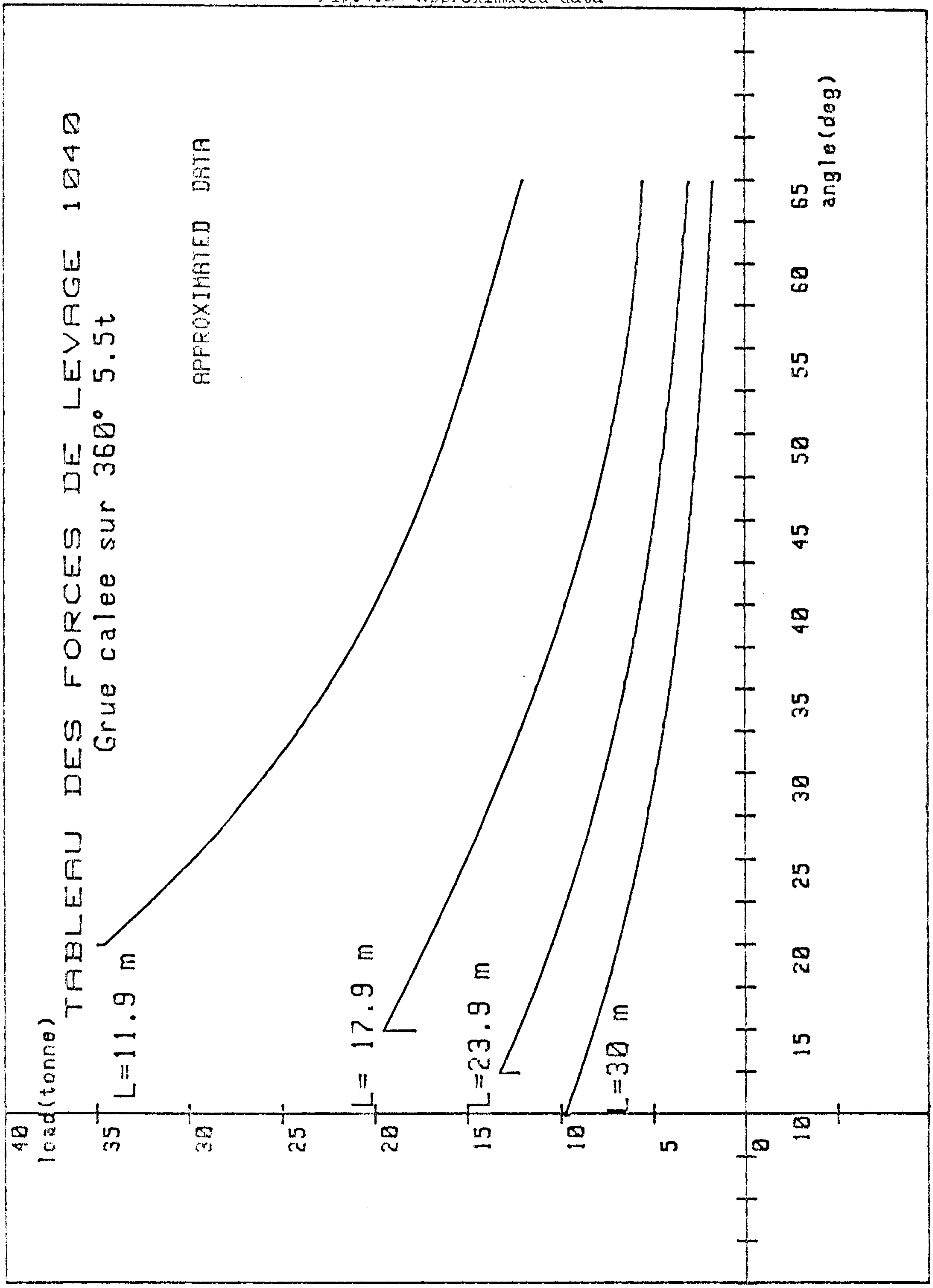
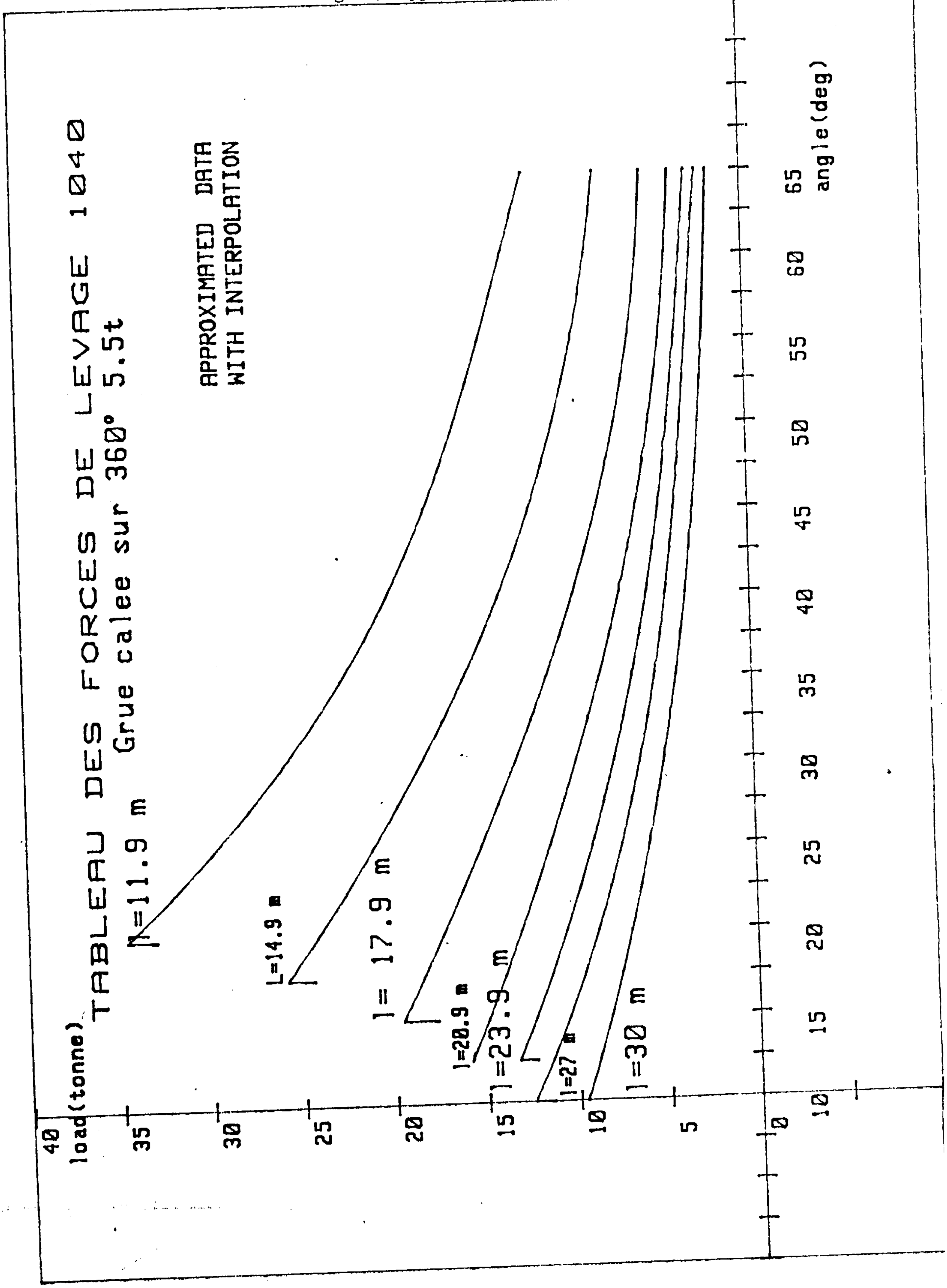


Fig.4.3 Approximated data with interpolation



4.2 RELATIVE ERRORS

4.2.1 Relative Error as Function of the Angle

The relative error was calculated to show the goodness of the approximation. This relative error was computed, first as function of the angle, and second as function of the length.

First, consider the relative error as function of the angle. Since the manufacturer provides only four tables for the study case, thus the relative errors were computed only for these curves without any extra curves. These curves were plotted and shown in Fig.4.4.

For L=11.9m, most of the relative error is less than 3%, except that for α =65°, where it rises up to 6%.

For L=17.9m, the error is partitioned into two intervals, first, less than 2% for α <52.5°, and second, between 4% and 7.5% for 52.5°< α <65°, with a peek at α =60°.

For L=23.9m, most of the error is less than 2% for α < 57.5° then it increases abruptly to 11.5% for α >60°.

Finally, for L=30.0m, the error lies between 2% and 4.5% for α < 45°, then it oscillates 4% and 10% for 45° < α < 65°. This oscillation is may be due to the error given in load tables. Examining all the curves, it is possible to say that the approximation is good for small angles where $\alpha < 45°$ with an error of 5%, and then it increases relatively for large angles because this parameter is rised to the power 3.

4.2.2 Relative Error as Function of the Length

Considering the relative error as function of the length, where the angle is constant at different values, starting from $\alpha = 20°$ up to $\alpha = 60°$ and increasing by a step of 10°. The corresponding error were calculated and graphs were plotted and shown in Fig.4.5.

For $\alpha = 20°$, the relative error is less than 2% for L<23.9m, then it increases to 4.5% when L=30.0m.

For $\alpha = 30°$, the error is less than 2% over all the range, thus, this error can be estimated to be a good approximation.

For $\alpha = 40°$, the error is less than 4% for all lengths, it is still a good approximation.

For $\alpha = 50°$, the error starts decreasing from 2.5% down to 1%, and then increases abruptly to 9%, for L=30.0m. This error can be interpreted again to the fact that the length parameter is rised to the power 3.

Finally, for $\alpha = 60°$, the error starts increasing then decreasing abruptly, this is due may be to an error at L=17.9m. Because, the error is less than 3% except for that length.

Examining closely the relative errors for both graphs, there exist some abnormalities, specially for the relative error as function of the length, where an abrupt discontinuity is sensed at L=19.0m. This abnormality can be interpreted as a change of some mechanical coefficients table that led to the allowed load tables. The maximum error in both cases is about 12%, thus it is possible to conclude that, this error is acceptable, because it is within the range of the 25% as required by the norm (DIN 15019).

In the derivation of the relevant equations, in conjunction with the crane model 1040, and the possible configuration, sixteen coefficients have been obtained. This will amount to 64 coefficients when the four configurations are considered. This approach permits the evaluation of the allowed load for any crane position. Note that, the allowed load does not characterize the crane capacity, as it changes with the different configurations.

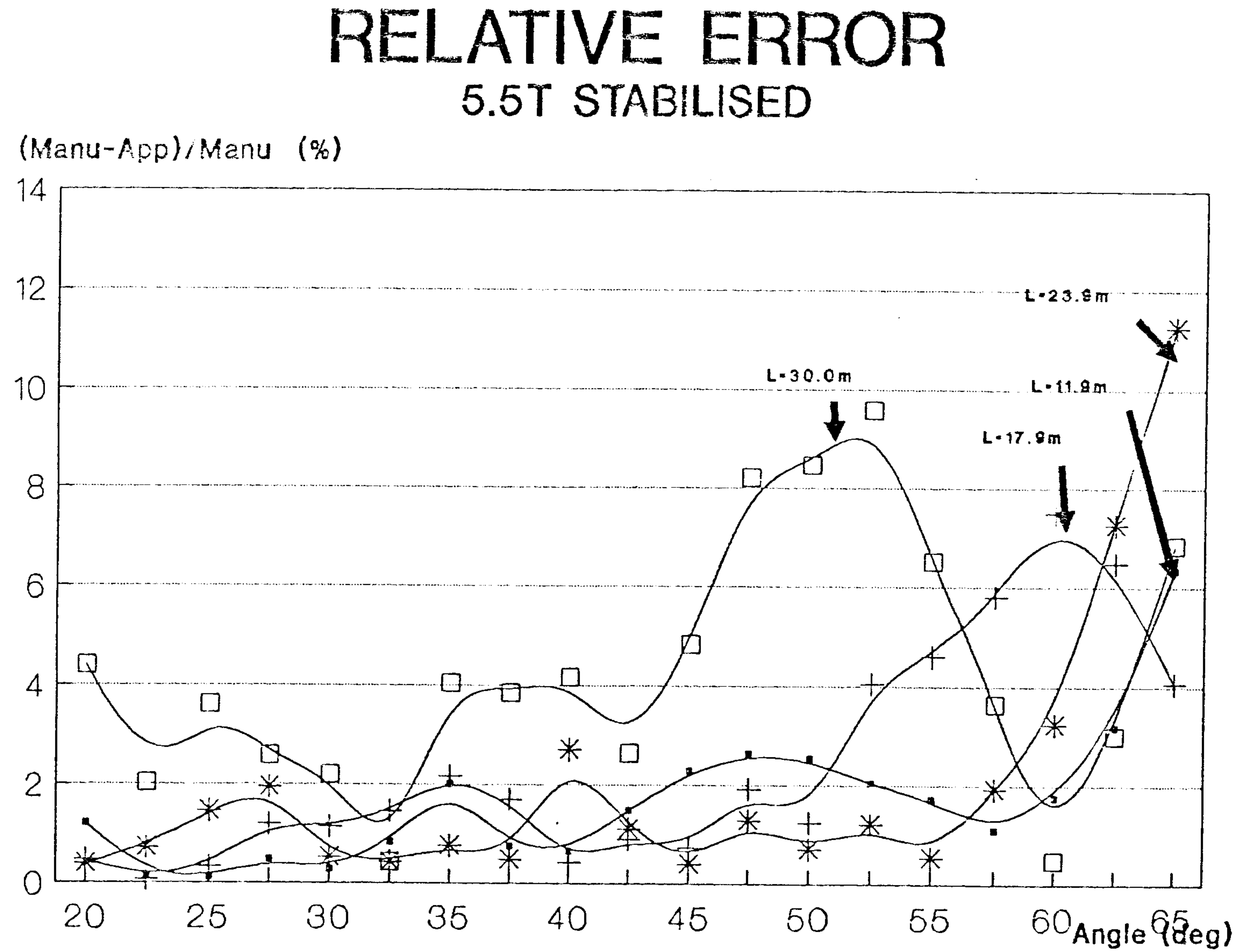


Fig.4.4 Relative error as function of the angle

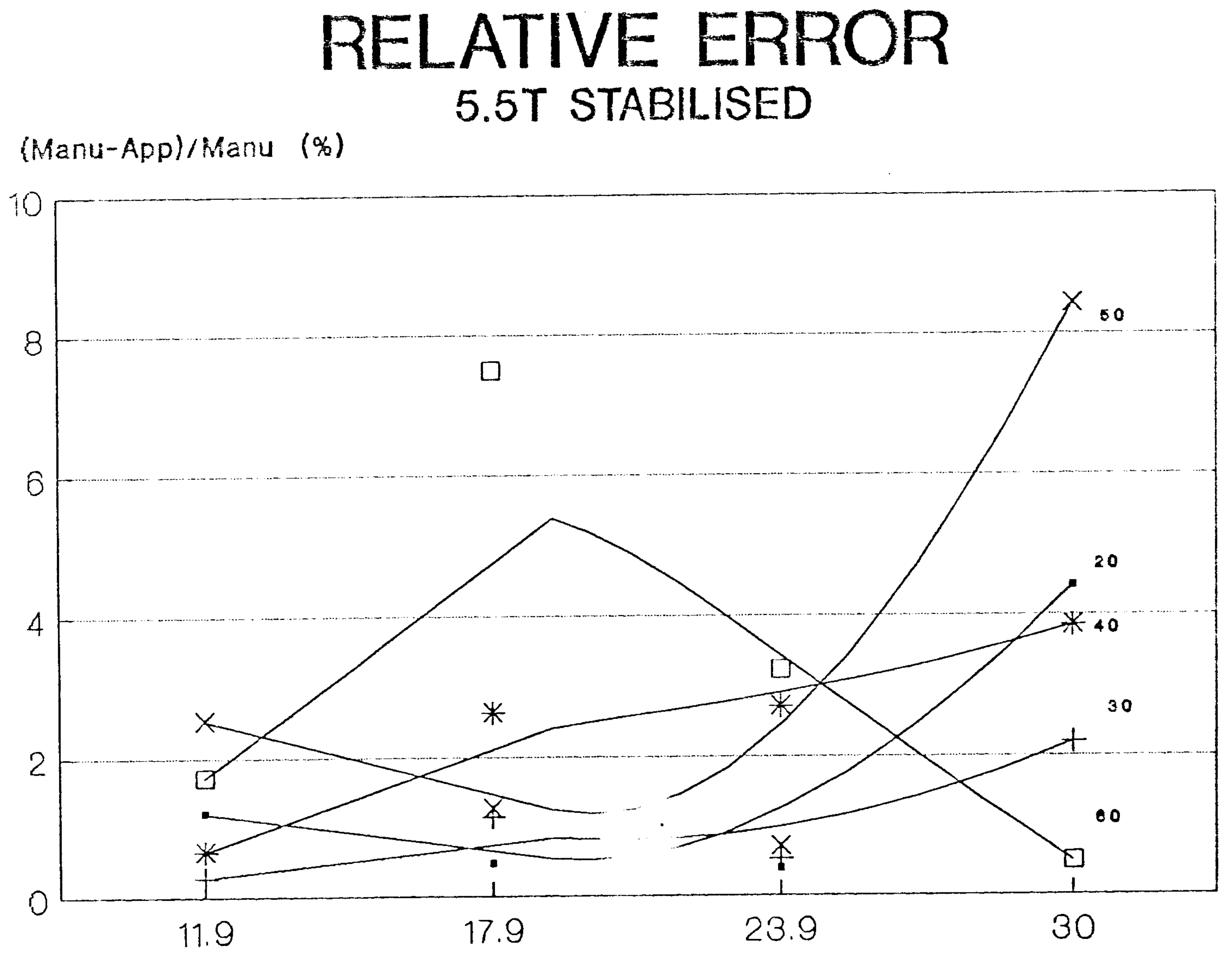


Fig.4.5 Relative error as function of the length

CRANE DATA PERSONALITY
"ENMTP – CPG 1040"

$A_0 = 33178 \cdot 10^{-2}$	$A_1 = -156 \cdot 10^{-1}$	$A_2 = 3207 \cdot 10^{-4}$	$A_3 = -228 \cdot 10^{-5}$
$B_0 = -3771 \cdot 10^{-2}$	$B_1 = 2009 \cdot 10^{-3}$	$B_2 = -4424 \cdot 10^{-5}$	$B_3 = 3255 \cdot 10^{-7}$
$C_0 = 1531 \cdot 10^{-3}$	$C_1 = -8772 \cdot 10^{-5}$	$C_2 = 1998 \cdot 10^{-6}$	$C_3 = -1494 \cdot 10^{-8}$
$D_0 = -2091 \cdot 10^{-5}$	$D_1 = 1253 \cdot 10^{-6}$	$D_2 = -2909 \cdot 10^{-8}$	$D_3 = 2195 \cdot 10^{-9}$

CRANE STABILISED ON 360° - 5.5 t COUNTERWEIGHT - 9 SHOOTS
- NO EXTENSION

$A_0 = 15664 \cdot 10^{-2}$	$A_1 = -5597 \cdot 10^{-3}$	$A_2 = 7322 \cdot 10^{-5}$	$A_3 = -2598 \cdot 10^{-7}$
$B_0 = -1259 \cdot 10^{-2}$	$B_1 = 3342 \cdot 10^{-4}$	$B_2 = -2067 \cdot 10^{-6}$	$B_3 = -1555 \cdot 10^{-8}$
$C_0 = 4054 \cdot 10^{-4}$	$C_1 = -7792 \cdot 10^{-6}$	$C_2 = -2815 \cdot 10^{-8}$	$C_3 = 4043 \cdot 10^{-8}$
$D_0 = -474 \cdot 10^{-5}$	$D_1 = 6721 \cdot 10^{-8}$	$D_2 = 1061 \cdot 10^{-9}$	$D_3 = -2344 \cdot 10^{-9}$

CRANE ON WHEELS - 5.5 t COUNTERWEIGHT - 9 SHOOTS
- NO EXTENSION

$A_0 = 309$	$A_1 = -1316 \cdot 10^{-2}$	$A_2 = 2447 \cdot 10^{-4}$	$A_3 = -1631 \cdot 10^{-7}$
$B_0 = -35$	$B_1 = 1727 \cdot 10^{-3}$	$B_2 = -3557 \cdot 10^{-5}$	$B_3 = 2519 \cdot 10^{-7}$
$C_0 = 1429 \cdot 10^{-3}$	$C_1 = -7705 \cdot 10^{-5}$	$C_2 = 1663 \cdot 10^{-6}$	$C_3 = -1205 \cdot 10^{-8}$
$D_0 = -1965 \cdot 10^{-5}$	$D_1 = 1119 \cdot 10^{-6}$	$D_2 = -2476 \cdot 10^{-8}$	$D_3 = 1813 \cdot 10^{-10}$

CRANE STABILISED ON 360° - 2.0 t COUNTERWEIGHT - 9 SHOOTS
- NO EXTENSION

$A_0 = -3712 \cdot 10^{-1}$	$A_1 = 497 \cdot 10^{-2}$	$A_2 = -1735 \cdot 10^{-4}$	$A_3 = 1563 \cdot 10^{-6}$
$B_0 = 7912 \cdot 10^{-2}$	$B_1 = -1347 \cdot 10^{-3}$	$B_2 = 379 \cdot 10^{-4}$	$B_3 = -3142 \cdot 10^{-7}$
$C_0 = -4737 \cdot 10^{-3}$	$C_1 = 7777 \cdot 10^{-5}$	$C_2 = -2082 \cdot 10^{-6}$	$C_3 = 1686 \cdot 10^{-8}$
$D_0 = 8797 \cdot 10^{-5}$	$D_1 = -1303 \cdot 10^{-6}$	$D_2 = 3408 \cdot 10^{-8}$	$D_3 = -2727 \cdot 10^{-10}$

CRANE ON WHEELS - 2.0 t COUNTERWEIGHT - 9 SHOOTS
- NO EXTENSION

CRANE DATA PERSONALITY
"ENMTP – CPG 1040"

Designation	Values	Comments
L_v	3.40 m	Length from pivoting axis to the hydraulic jack fixation
h	0.81 m	Height from pivoting axis to the crane chassis
e_1	0.28 m	Length of the upper end boom to the tension T
e_2	0.61 m	Length from upper end boom to lifted load P
e_3	0.58 m	Length from the hydraulic jack articulation to the boom fixation
O'A	0.97 m	Distance of the rotational axis to the hydraulic jack
H	2.80 m	Height from the earth to the crane chassis
ψ	1.2	Safety coefficient

CHAPTER 5

SYSTEM HARDWARE

5.1 System description.

5.2 System hardware.

5.2.1 Reset interrupt.

5.2.2 Storage memory organisation.

5.2.3 Analog to digital converter interfacing.

5.2.4 Digital to analog converter interfacing.

5.2.5 Data bus display.

5.2.6 System interrupt.

CHAPTER 5

5.1 SYSTEM DESCRIPTION

The system description is shown in Fig.2.2, which illustrates the position of the transducers on the crane, and the display console unit.

On the display console unit, commutators are provided from S_1 to S_7, to set the crane configuration, and the data to be displayed. The description of these switches is as follows:

S_1:
1, displays angle & allowed load
2, displays free range & lifted load
3, displays length & height

S_2: use of 5.5 or 2.0 tonnes counterweight

S_3: use of outriggers or wheels

S_4: use of extension boom or not

S_5 & S_6: shoots in making the cable

0 0 --------> 3 shoots

0 1 --------> 4 shoots

1 0 --------> 5 shoots

1 1 --------> 9 shoots

S_7:
1, normal scaling
2, offset

The offset is used for an unskilled operator who is not familiar with this crane type to offer more safety, meaning thereby, the system will be in the warning state at 85% of the maximum capacity, which represents 34 tonnes, instead of 40 tonnes.

5.2 SYSTEM HARDWARE

The system hardware is based on the Motorola MC 68000, running at 8 Mhz clock cycle which is sufficient to monitor the load, because of the following reasons:

- The crane orientation speed is 2.1 rpm.
- The maximum lifted time is 50 sec at 82°.
- The time taken to move out the maximum boom length (30.0m) is 100 sec.

Then, the orientation time taken by the crane to swap 360° is 2.1 x 60 sec. The critical time to execute the main program is approximately 200 msec, thus for this short time period, the boom can swap by an angle of:

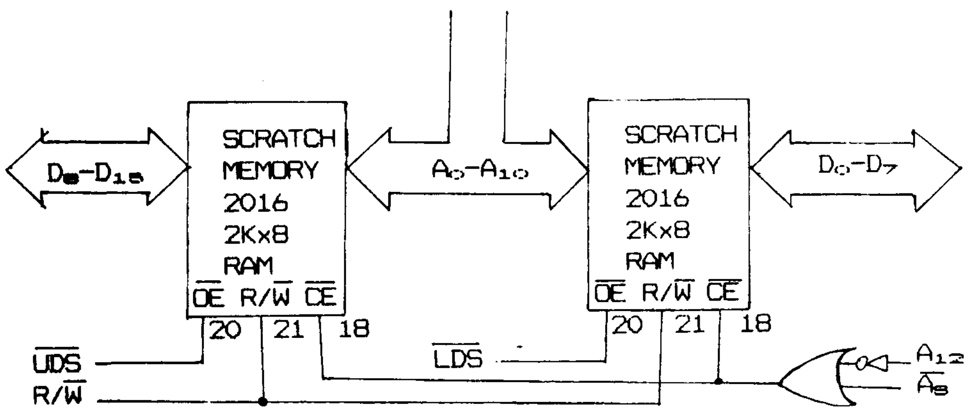
$$\frac{360° \times 200.10^{-3}}{2.1 \times 60} = .6°$$

the lift angle can only change by:

$$\frac{82° \times 200.10^{-3}}{50} = .328°$$

These results are negligible to provide any danger to the crane manoeuvre. The system hardware is shown in Fig.5.10.

operation as the 68000 writes a word of data to a RAM memory. The write bus cycle that is performed to write data to the scratch memory storage begins with the 68000 output the address of the storage location that is to be accessing on address bus lines A_1 through A_{23}. Then it switches the $\overline{AS}$ output to its active 0 logic level. This signal tells external circuitry, that a valid address is available on the bus. At the same time, the 68000 sets $R/\overline{W}$ to logic 0 to signal that a write bus cycle is in progress. Moreover, it sets both $\overline{UDS}$ and $\overline{LDS}$ to their active 0 logic level to signal that a word data transfer is to take place over the data bus. Finally, the word of data that is to be written into memory is output on the data bus lines D_0 through D_{15}.



A_{20}	A_{16}	A_{12}	A_8	A_4	A_0	
000 0	000 0	000 0	000 0	000 0	000 0	lowest RAM add. 001000
000 0	000 0	000 0	011 1	111 1	111 1	highest RAM add. 0017FF

Fig.5.4 2K RAM selection

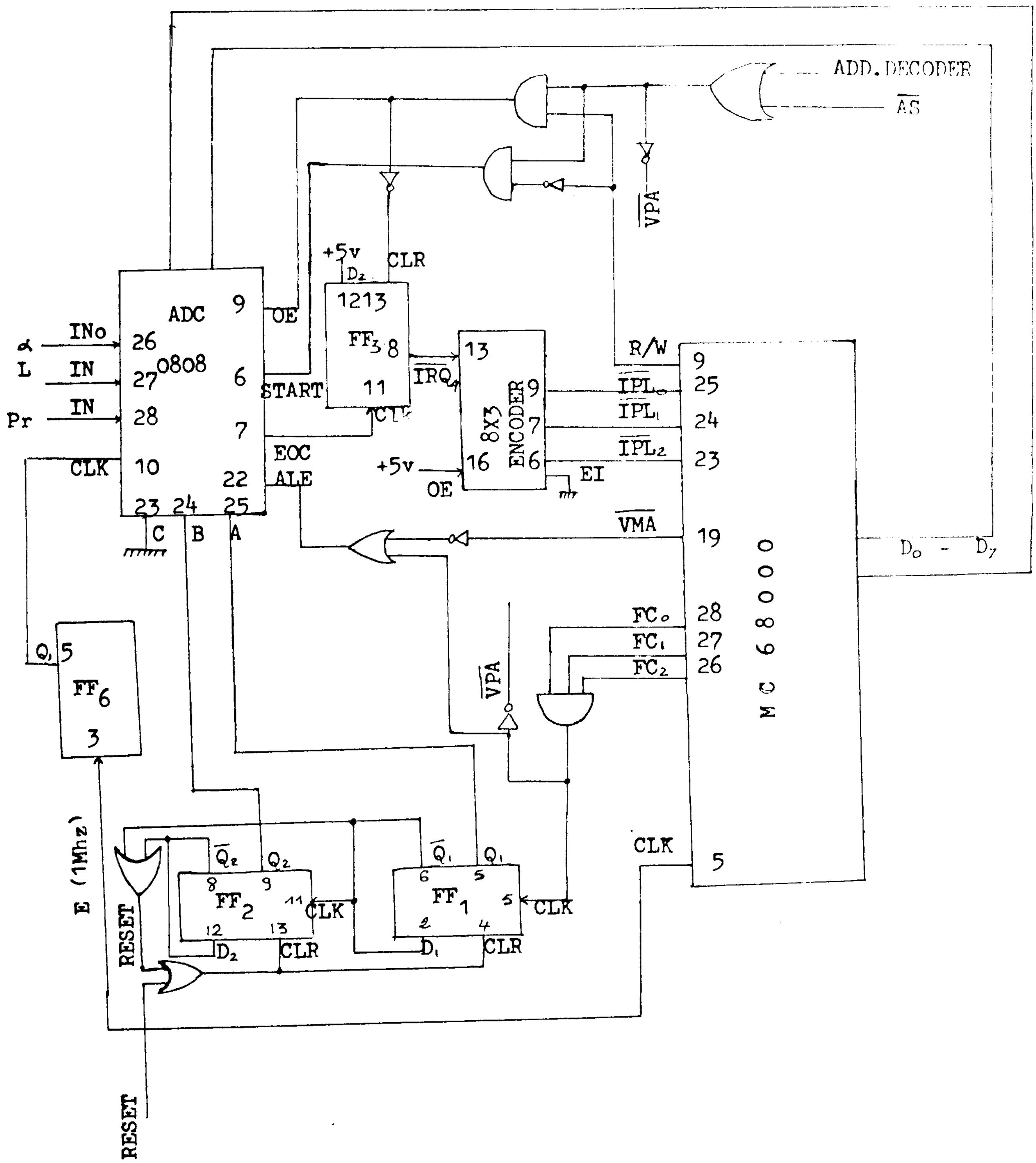


Fig.5.5 A/D 0808 Interfacing

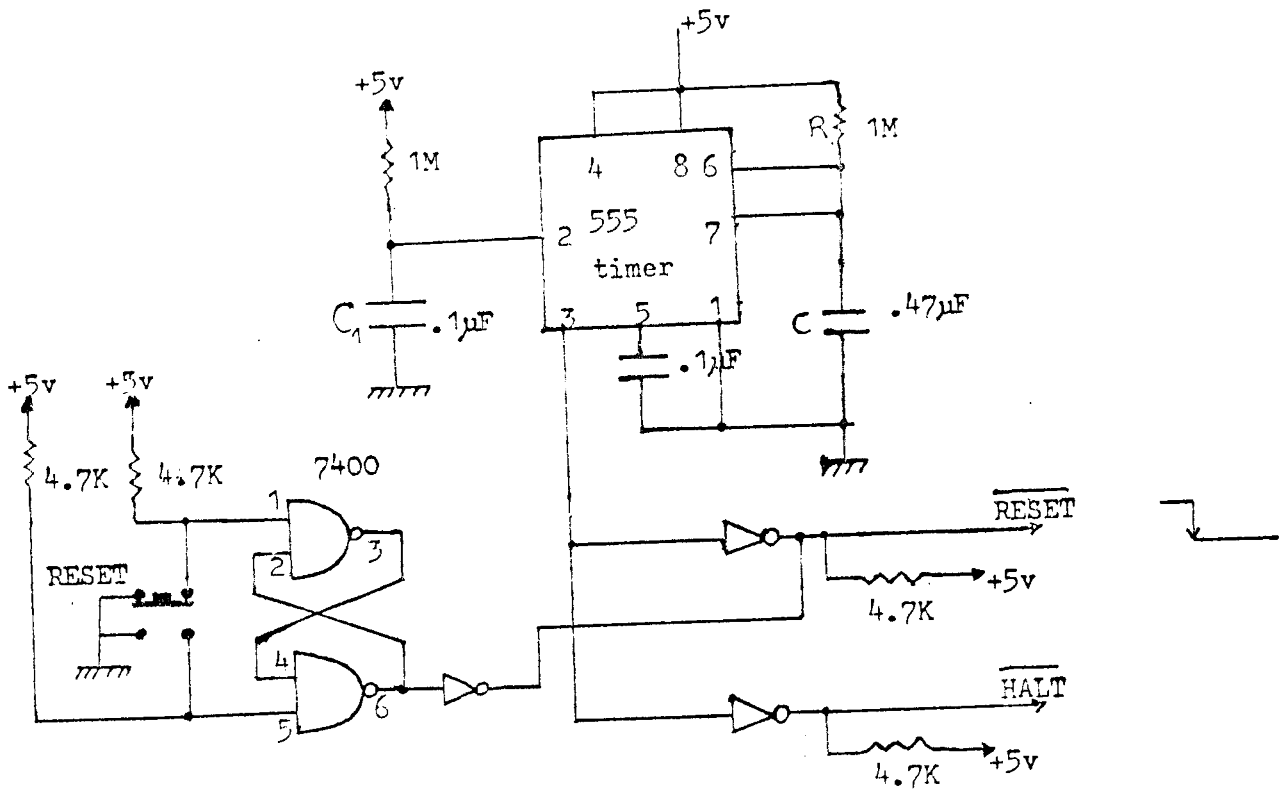


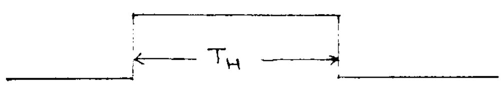
Fig.5.1 Interrupt interfacing circuit.

5.2.1 Reset Interrupt

The system initialization is performed either at power up, or by depressing the push-bottom located on the display console unit. It consists of a reset flip-flop constructed from two of the NAND gates on the 74LS00 and a monostable multivibrator formed with the 555 timer as shown in Fig.5.1.

The monostable multivibrator circuit is used to initialize the complete microprocessor-based system at power ON. When the power switch is turned ON, capacitor C_1 which is connected from pin 2 of the 555 to ground, acts like a short circuit to ground, and forces the trigger. $\overline{TRIG}$ input of the 555 timer to logic 0. This causes the output at pin 3 to switch to the 1 logic level. As time elapes, C_1 charges toward the 1 logic level threshold of the $\overline{TRIG}$ input.. As it exceeds this value. the ***OUTPUT*** returns to the 0 logic level. In this way. a single pulse to the 1 logic level is produced at the timer's ***OUTPUT*** pin 3.

The one shot pulse is generated as follows:



$$T_H = 1.1\ RC$$

where $R = 1\,M\Omega, \quad C = 0.47\,\mu F$

$$T_H = 1.1.10^6 \times 0.47.10^{-6} = 517\ ms$$

This is a good choice because the system reset requires a duration between 350 and 600 ms.

The system can also be reset without turning OFF the main power. This is done by depressing the reset push-button placed in front of the operator. This reset, when depressed gives 1 at pin 6 of the flip-flop, and as it is released the output is reset to 0. This mechanism represents what is called a warm start. The main objective of this push-button reset is to avoid the operator to switch OFF the system, select a new configuration, switch ON again the system, or after any halt state of the processor.

5.2.2 Storage Memory Organization

5.2.2.1 Program and Data Storage Memory

Figure 5.2 shows the 68000 MPU with the program and data storage part. Notice that, it involves three key elements of circuitry: the EPROM, the EPROM address decoder, and the EPROM DTACK circuit.

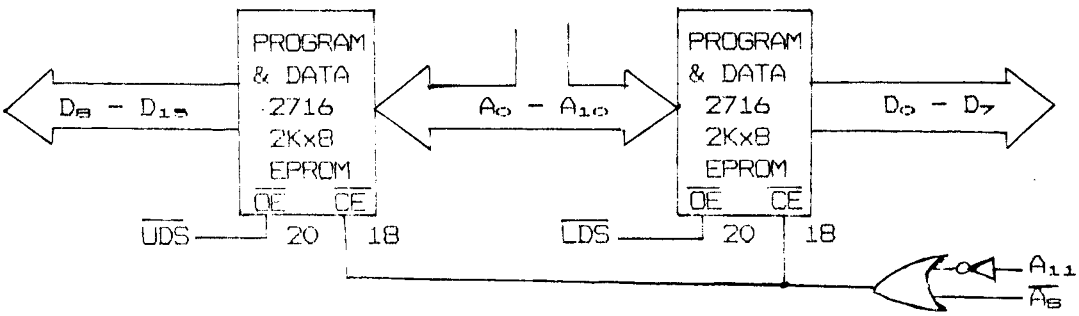
a/ The 2716 EPROM

The EPROM chip that will be using for program and data storage can hold 2x2048 eight bit words. Eleven address lines are required to form 2048 different combinations, since 2^{11}=2048. The 68000 has 23 address lines, so 12 lines

(A_{11} through A_{23}) are not required for address selection. We may use any, or all lines for chip selection, that is for determining whether or not we are accessing the EPROM.

b/ Chip select by address decoding

Figure 5.3 shows how 2 input OR gate selects the EPROM. This is the 4-K block from 000800_{16} to $000FFF_{16}$. Notice that the low order 11 address lines are used to select locations within the 4-K block, where the MPU supplies address information to both EPROM over address lines A_1 through A_{10}, the address map in Fig.5.9 shows that EPROM resides in two page of the 68000's address space, one used for the lower byte and the other is for the higher byte. It is in this section of memory that the instructions and the data crane personality are stored. The starting space memory is allocated with the exception vector.



A_{20}	A_{16}	A_{12}	A_8	A_4	A_0	
000 0	000 0	000 0	000 0	000 0	000 0	lowest EPROM address 000800
000 0	000 0	000 0	011 1	111 1	111 1	highest EPROM address 000FFF

Fig.5.3 The 2-K EPROM selection (Data and instruction)

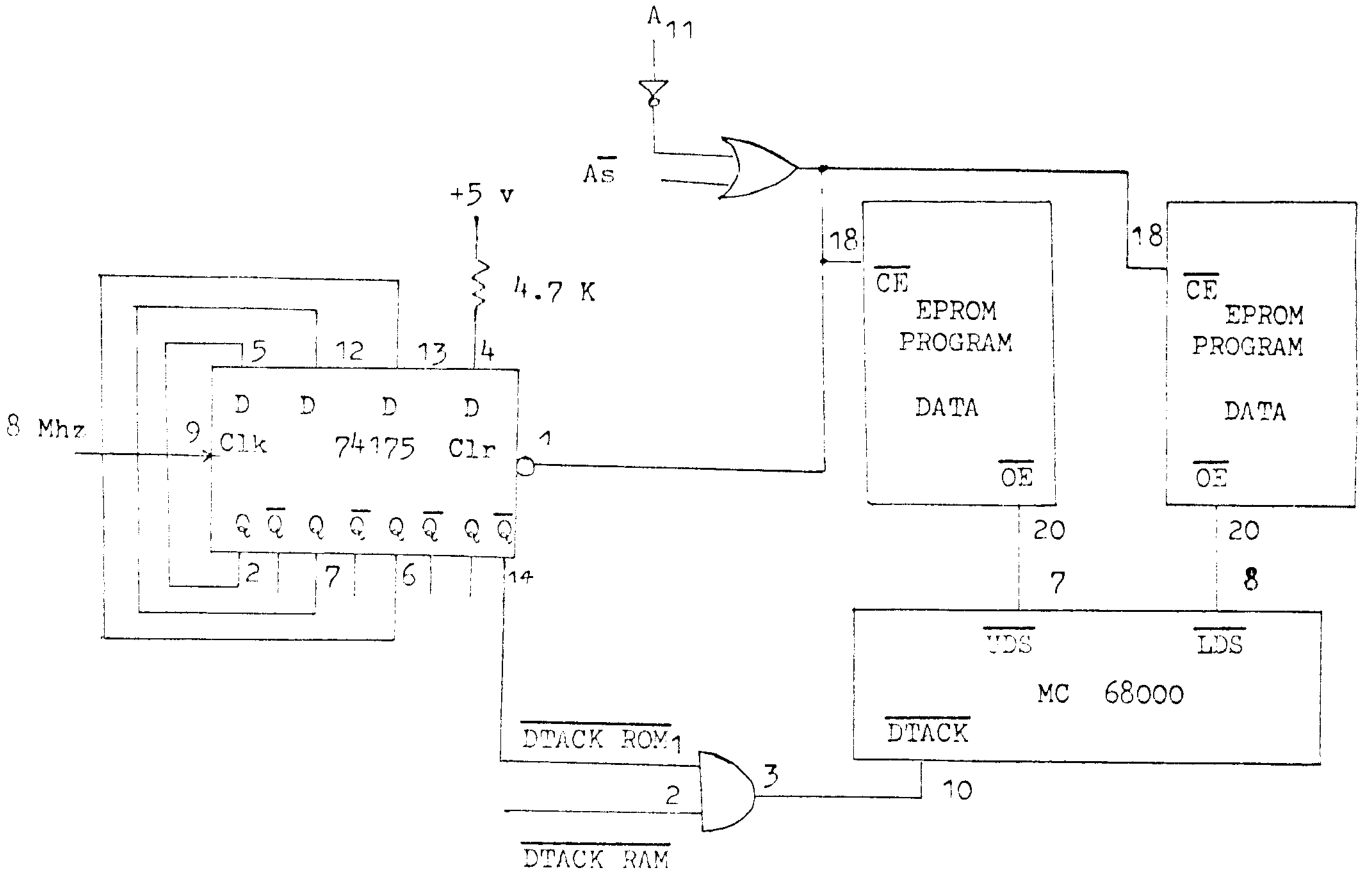


Fig 5.2 Program and Data storage memory.

Whenever an address in these ranges is output on the address bus lines A_1 through A_{23}, the address decoder circuit detects its occurrence and produce the EPROM enable signal.

c/ EPROM DTACK Signal

The EPROM DTACK circuit is used to produce the $\overline{DTACKROM}$ signal that tells the MPU to complete asynchronous bus cycles that are performed to the program memory. This circuit is actually a counter constructed from the D-type flip-flops of the 74LS175 IC. The flip-flops on this IC are connected to form a 4 bit binary counter. The clock input at pin 9 of this counter is supplied by the 8-Mhz clock signal. As a memory bus cycle is initiated to program memory, EPROM Enable is switched to 1 and the counter increments toward a count of 1000. When this count is reached, the $\overline{Q}$ output at pin 14 switches to the 0 logic level. This makes the signal $\overline{DTACKROM}$ to logic 0 and the output of the 74LS11 AND gate signals the 68000 that the bus cycle can be completed by switching $\overline{DTACK}$ to logic 0.

5.2.2.2 Scratch Memory

The scratch memory interface is similar to that described for the program and the data storage memory. Now that, It has been described the operation of the circuits involved in the memory interface of Fig.5.4, let us trace through their

5.2.3 ANALOG TO DIGITAL CONVERTER 0808

The A/D 0808 data acquisition device contains an 8 bit A/D converter, 8-channel multiplexer with an address input latch and associated control logic. For this application, it has been used only 3 input channels, IN_0, IN_1, and IN_2. The 8 conversions time are about 100µs, when using a 640 kHz clock, but can convert a single input in as little as approximately 50µs. One conversion takes 8 approximations, and one approximation takes 8 clock periods.

$$\Sigma \text{ conversion time} = 64 \text{ clk periods.}$$

5.2.3.1 Interfacing with the Microprocessor

Taking into account the parameters given by the data sheet:

1/ 3 channel select input (A, B, C).

2/ ALE is pulsed positively  to clock the address into the multiplexer address register.

3/ START is pulsed to begin the conversion internal register are cleared on the rising edge of this pulse and conversion is initiated on the falling edge. Conversion starts at the beginning of the next 8 clk cycle.

4/ EOC is low at the beginning of the next 8 clk and stay so until the end of conversion after 64 clocks.

5/ OE is rising high to enable the control outputs and data are read.

6/ Output buffers are necessary to interface with the external signal.

The A/D interfacing is shown in Fig.5.5, it illustrates the selection of the three parameters, the angle, the length, and the pressure needed for solving the derived equations is commanded by the two flip-flop FF_1 and FF_2. Since the system needs only three input parameters, thus two channel select (A and B) will be sufficient for selecting these inputs, the third channel select (C) is grounded.

At a reset, the output of the two flip-flops, FF_1 and FF_2, are at logic 0, this means that, the channel select inputs, are both set to logic 0 (A=0 and B=0) which allows the selection of the angle. The process of selection is illustrated in Fig.5.6.

The $\overline{VMA}$ signal is used to trigger the ALE of A/D, at the starting of the operation which accede to the angle input. The CPU writes a dummy data on the address specified by the address decoder to write on the A/D, this causes the signals to be set. $\overline{AS}=0, R/\overline{W}=0$ output of the address decoder is 1, now the start input is at logic level 1. When the conversion is accomplished the A/D will generate 1 through the EOC pin, this signal is used to trigger the flip-flop, FF_3 to select one priority level through the 8x3 encoder. The three outputs of the encoder are connected to $\overline{IPL_0}$, $\overline{IPL_1}$, $\overline{IPL_2}$, when the processor is interrupted, it will automatically put $\overline{F_{c0}}$, $\overline{F_{c1}}$, $\overline{F_{c2}}$ at 1, these 1 are used to clock the FF_1. This causes a change on the output of the FF_1, which switches to logic 1, thus, the two flip-flops, FF_2 and FF_1 are now at logic 01 respectively, this combination allows the selection of the length, this signal is inturn through the inverter to trigger the $\overline{VPA}$ signal to the CPU.

To read the conversion data, the CPU sends a read cycle and trigger the output which enable to latch data through the data bus. This procedure is used each time when the CPU needs to convert the three input parameters.

The $\overline{DTACK}$ circuit is just a counter which starts counting after the CPU address the A/D peripheral, at the end of a counts/(one bus cycle), it sends a signal at $\overline{DTACK}$ input to allow the CPU to end the cycle. The same procedure of reading data, is used to read the configuration, which allows the processor to select the corresponding coefficients of the allowed load given by the Eq.4.4.

After converting the three variables, and reading the proper coefficients of the selected configuration, the processor is ready to compute the four needed values which are:

- The allowed load $A_L(\alpha, L)$
- The lifted load M
- The free range Y_0
- The height Z_0

and through the digital to analog converter (DAC 1408). The processor displays permanently the percentage load ratio to the analog coded display.

Out FF_1	Out FF_2	Input A	Input B	Input C	Var.
0	0	0	0	0	α
1	0	1	0	0	L
0	1	0	1	0	P_R

Fig.5.6 Selection Input Variable

5.2.4 DIGITAL TO ANALOG CONVERTER

The DAC 1408 is an 8-bit multiplying Digital-to-Analog Converter, designed for a system where the output current is a linear product of an 8-bit digital word and an analog input voltage. The specifications are:

1/ 8-bit accuracy available in both temperature ranges, relative accuracy is ± 0.19% maximum error

2/ Fast setting time 300 ns typical

3/ Non-inverting digital inputs are MTTL and CMOS compatible

4/ Output voltage swing +0.4 volt to -5.0 volts

5/ Standard supply voltages +5.0 V and -5 V to -15 V

5.2.4.1 Interfacing with the Microprocessor

Notice that, the DAC 1408 do not have a latch, so it is necessary to add an 8-bit latch, the IC 74LS373, to be able to trigger it when ever a new data is set. Figure 5.7 shows the circuit diagram using the 74LS373, and the DAC 1408. Notice also that, a separate -15 volts supply is required for the DAC 1408. The output is capable of assuming 256 different levels, so a nearly continuous waveform can be produced.

The address decoding of the 8-bit latch data will be converted in about 300 ns, the analog signal will enter an operational amplifier LM 741 connected in such a way so as to make an adjustment to the reference of the analog display, which is done during calibration.

The analog display is portioned into three ranges described as follows:

-Dark range ---> Load ratio is less than 65%.

-Blank range ---> Load ratio is between 65% and 85%.

-Doted range ---> Load ratio is between 85% and 100%.

If the lifted load exceeds 100%, a sonar alarm is activated to indicate the overloading and the lifted crane movement is immediately stopped.

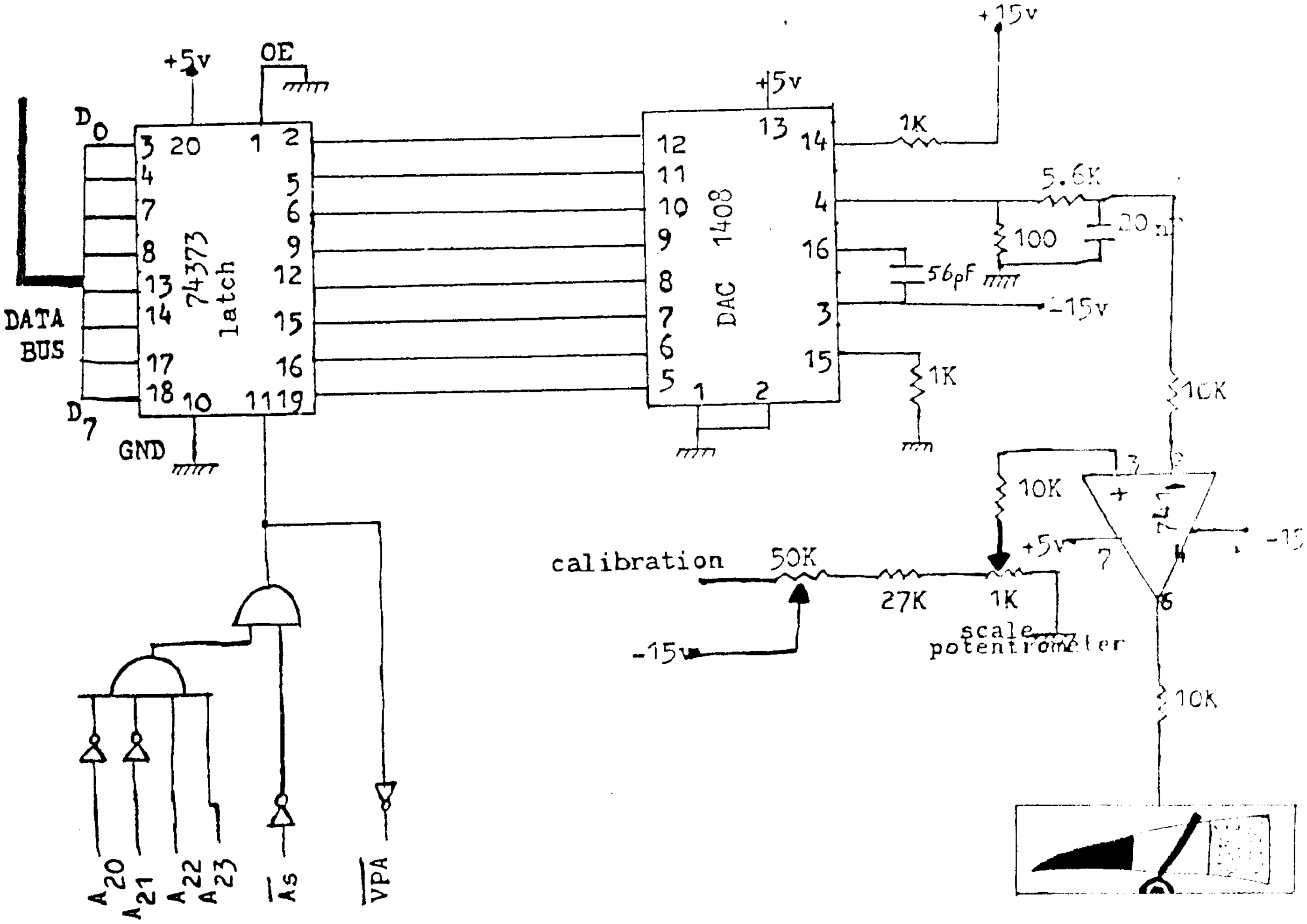


Fig.5.7 D/A 1408 interfacing

5.2.5 DATA BUS DISPLAY

There exists a very convenient (but rather expensive) IC package that will not only latch 4-bits of data, but decode the data to a hex digit 0 through F and display it on a 5x7 dot-matrix LED. It is called a TIL 311. Figure 5.8 shows how they can be connected to the 68000 data bus to display the needed parameters.

FUNCTION	TYPE	ADDRESS in HEXADECIMAL
Data & Program	EPROM I,II	000800 - 000FFF
Scratch Memory	RAM	001000 - 0017FF
Peripherals	ADC 0808	B00000 - BFFFFF
	DAC 1408	C00000 - CFFFFF
	Config.	900000 - 9FFFFF
	Up. Display	E00000 - EFFFFF
	Low. Display	A00000 - AFFFFF
	oil-pump relay	D00000 - DFFFFF

Fig 5.9 Memory Address Map

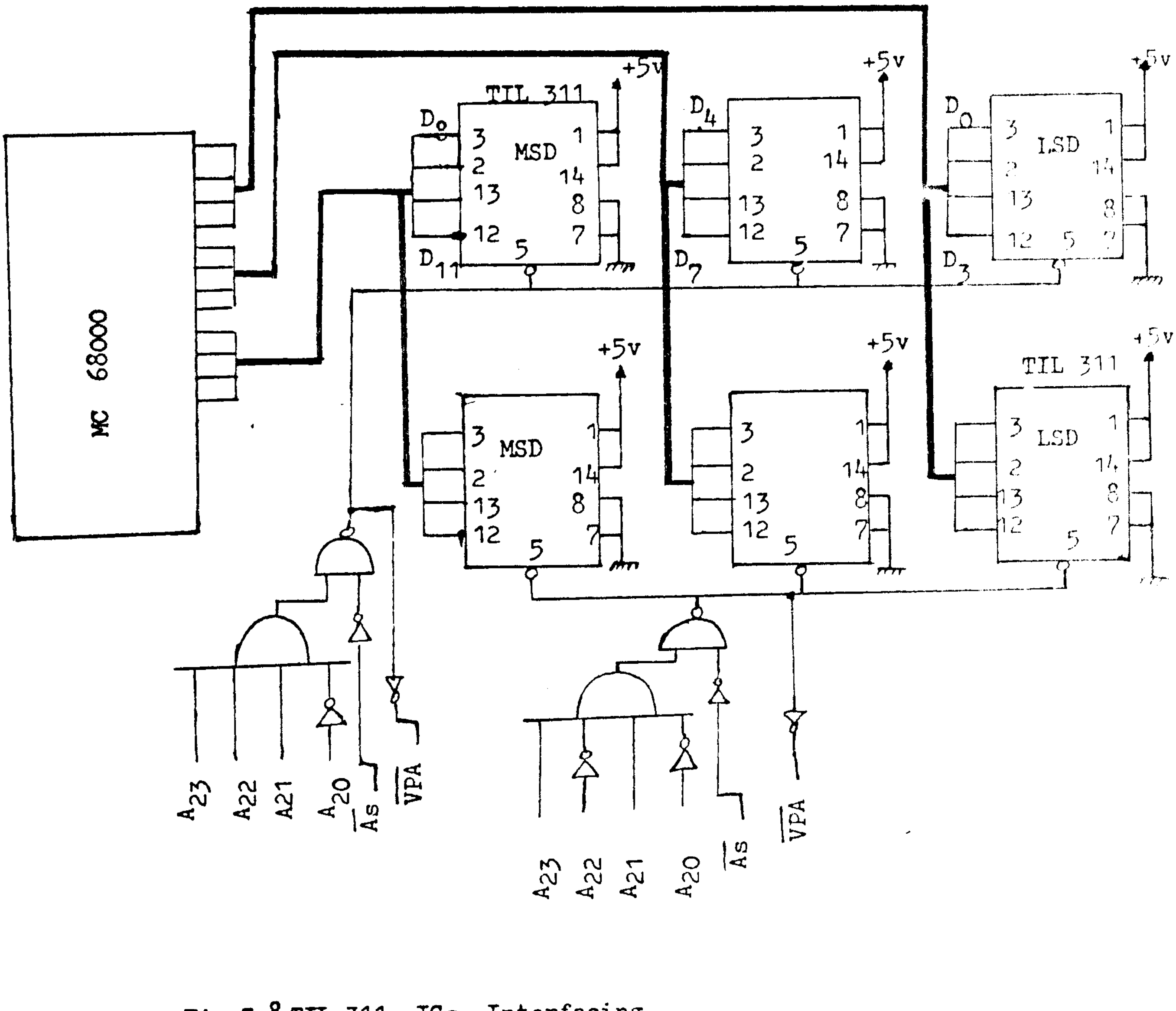


Fig.5.8 TIL 311 ICs Interfacing

5.2.6 SYSTEM INTERRUPT

Two more switches are provided to the system, and they are capable of stopping the crane lifting movement. The first one, is the hoist switch, which can be ON only when the lifted load reaches the boom top. This detection is used to avoid collision between the lifted load and the boom end frame, and it is based on a single pole switch placed on the appropriate place. The second, is the orientation switch, which is used to detect the position of the rotating disc where the boom is mounted. If the wheel sitting mode is chosen by the operator, the boom should be oriented only to the rear. Otherwise, this switch will be ON. Both of these switches, when activated put the CPU in the halt state, and switch on the corresponding lamp on the console unit.

They are mounted in parallel so that only a logic 1 will be sufficient to stop the crane movement by energizing the oil-pump relay through the power transistor. The hoist switch is used to turn on the lamp , and the orientation switch is used to turn on the lamp . The FF_8 is used when a dummy address is signalled by the CPU in case of overloading and it will maintain the power transistor ON until the generation of a reset signal.

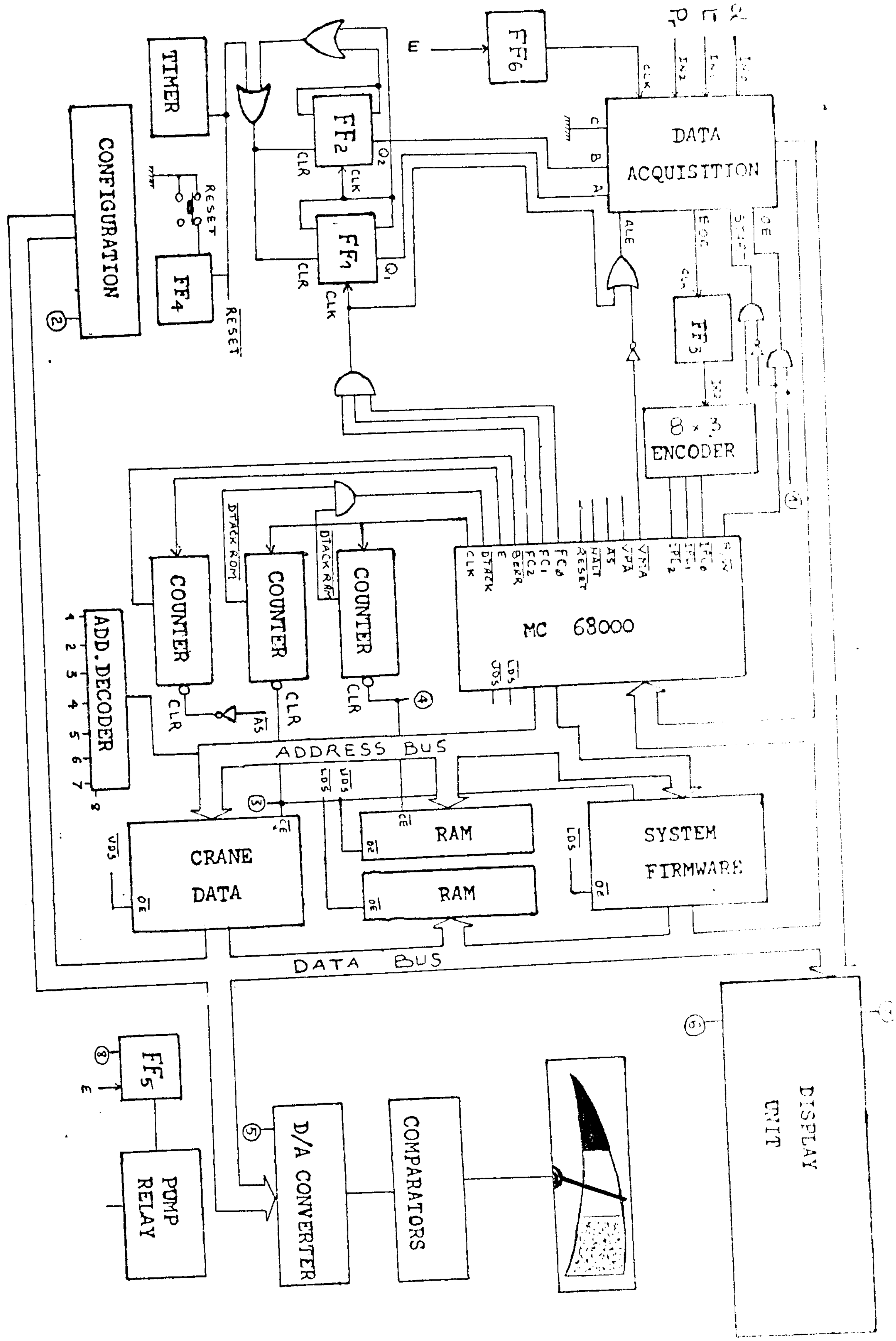
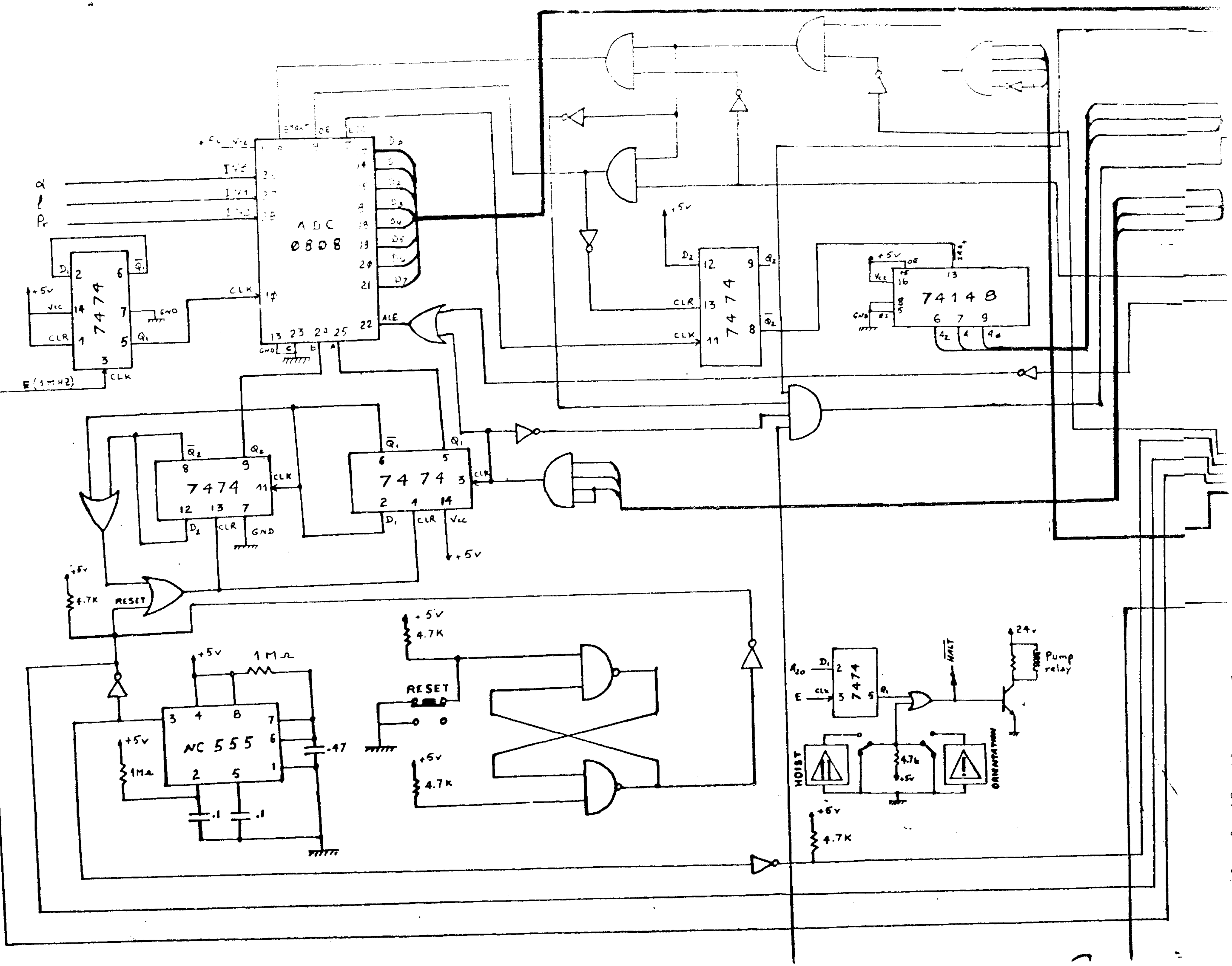
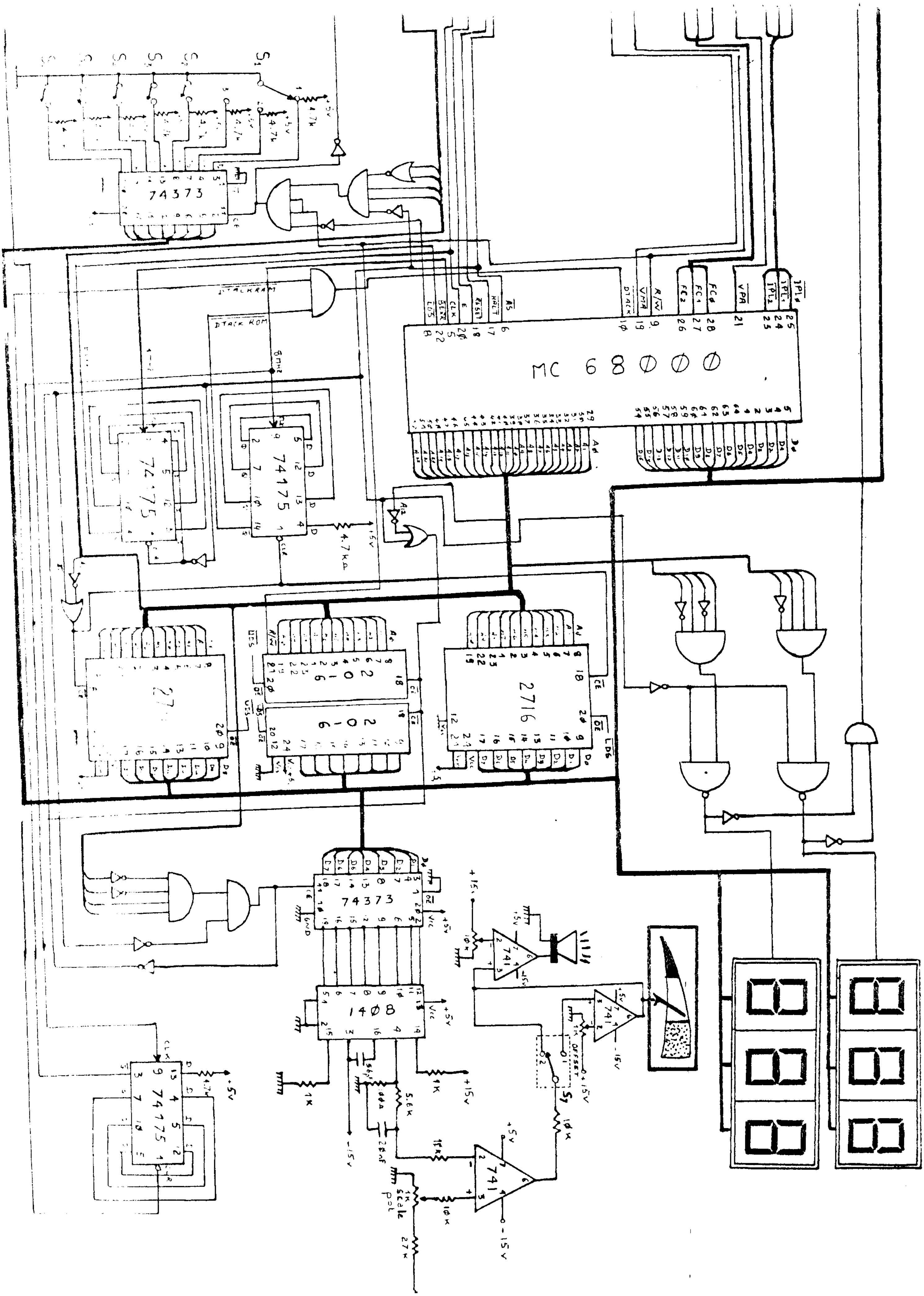


Fig.5.10 System Hardware



ADC
0808
ALE
CLK
7474
74148
NC 555
1MΩ
.47
.1
RESET
+5v
4.7K
Pump
relay
24v
HALT
HOIST
ORIENTATION
E (1 MHZ)
GND
Vcc
CLR


MC 68000
74373
74175
2716
1408
741
74373
74175
741
741

CHAPTER 6

SYSTEM SOFTWARE

6.1 System software.

6.1.2 Resolution process of the allowed load.

6.1.3 Resolution process of the lifted load.

6.1.4 Resolution process of the free range and the height.

6.2 Main software routine.

6.3 Exception vector.

6.3.1 Exception vector table.

6.1 SYSTEM SOFTWARE

The system software was developed on the Motorola [illegible] 68000 educational microcomputer, (MEX68KECB/D2). This microcomputer is an educational tool, with a minimum configuration constituted by a terminal, a printer, and an audio cassette tape recorder. All the program routines were developed in assembly language. The software used consists of solving the derived equations, which allows the monitoring of the lifted load and the data to be displayed. The computation of these equations will be based on the [illegible] solution to facilitate the programming. As an example let us trace a BCD addition. If two numbers are to be added, they are supposed to be in an integer form with their exponents ($0.021 = 21.10^{-3}$). Two cases are considered, either the two numbers have exponent or only one number which has an exponent. First, if there is only one number with its exponent, thus, the resolution process is:

$$a.10^{-n} + b = (a \text{ "shifted n times right"} + b)10^{-n}$$

Second, if the two numbers are with their exponents, thus, the resolution process is:

$$a.10^{-n} + b.10^{-m} \quad : \text{with } m < n \text{ if not exchange}$$

$$= (b \text{ "shifted m times left"} + a)10^{-n}$$

Based on this technique, all the coefficients of the equations are in integer forms, and the resolution process adopted is explained below.

6.1.2 Resolution Process of the Allowed Load

First of all, the computation of the allowed load $A_L(\alpha, L)$ given in Eq.4.4, is based on the proper coefficients of the crane model 1040. The process of resolution is as follows:

$$
\begin{aligned}
A_L(\alpha, L) = {} & a_1 10^{-2} - b_1 10^{-1}\alpha + c_1 10^{-4}\alpha^2 - d_1 10^{-5}\alpha^3 \\
& + \left(-a_2 10^{-2} + b_2 10^{-3}\alpha - c_2 10^{-5}\alpha^2 + d_2 10^{-7}\alpha^3\right)L \\
& + \left(a_3 10^{-3} - b_3 10^{-5}\alpha + c_3 10^{-6}\alpha^2 - d_3 10^{-8}\alpha^3\right)L^2 \\
& + \left(-a_4 10^{-5} + b_4 10^{-6}\alpha - c_4 10^{-8}\alpha^2 + d_4 10^{-9}\alpha^3\right)L^3
\end{aligned}
$$

All the exponents can be represented as coefficients for simplification:

$$
\begin{aligned}
AL(\alpha, L) = {} & \left(2a_1 - 1b_1\alpha + 4c_1\alpha^2 - 5d_1\alpha^3\right) \\
& + \left(-2a_2 + 3b_2\alpha - 5c_2\alpha^2 + 7d_2\alpha^3\right)L \\
& + \left(3a_3 - 5b_3\alpha + 6c_3\alpha^2 - 8d_3\alpha^3\right)L^2 \\
& + \left(-5a_4 + 6b_4\alpha - 8c_4\alpha^2 + 9d_4\alpha^3\right)L^3
\end{aligned}
$$

By executing the shifting left operator with respect to the highest exponent we obtain the following form:

$$AL(\alpha, L) = (3a_1 - 4b_1\alpha + 1c_1\alpha^2 - d_1\alpha^3)5$$
$$+(-5a_2 + 4b_2\alpha - 2c_2\alpha^2 + d_2\alpha^3)7L$$
$$+(5a_3 - 3b_3\alpha + 2c_3\alpha^2 - d_3\alpha^3)8L^2$$
$$+(-4a_4 + 3b_4\alpha - 1c_4\alpha^2 d_4\alpha^3)9L^3$$

At this level we multiply by L coefficient and apply the shift operation over the whole expression, usually with respect to the highest exponent.

$$AL(\alpha, L) = \{4(3a_1 - 4b_1\alpha + 1c_1\alpha^2 - d_1\alpha^3)$$
$$+2(-5a_2L + 4b_2\alpha L - 2c_2\alpha^2 L + d_2\alpha^3 L)$$
$$+1(5a_3L^2 - 3b_3\alpha L^2 + 2c_3\alpha^2 L^2 - d_3\alpha^3 L^2)$$
$$+(-4a_4L^3 + 3b_4\alpha L^3 - 1c_4\alpha^2 L^3 + d_4\alpha^3 L^3)\}9 \qquad (6.1)$$

how to choose the standard length number, the expected largest term in the Eq.6.1 is the term given by: $d_4\alpha^3L^3$ Notice that, the maximum value of the angle and the length as they are defined in their corresponding configuration are $\alpha = 65°, L = 30m$ respectively, thus the largest term will take 44 bits. Since we expect some shifting it has been decide that, each term is to be defined in a 64-bits length. The algorithm for solving the allowed load equation is given in Fig.6.1, which illustrates all the steps of resolution.

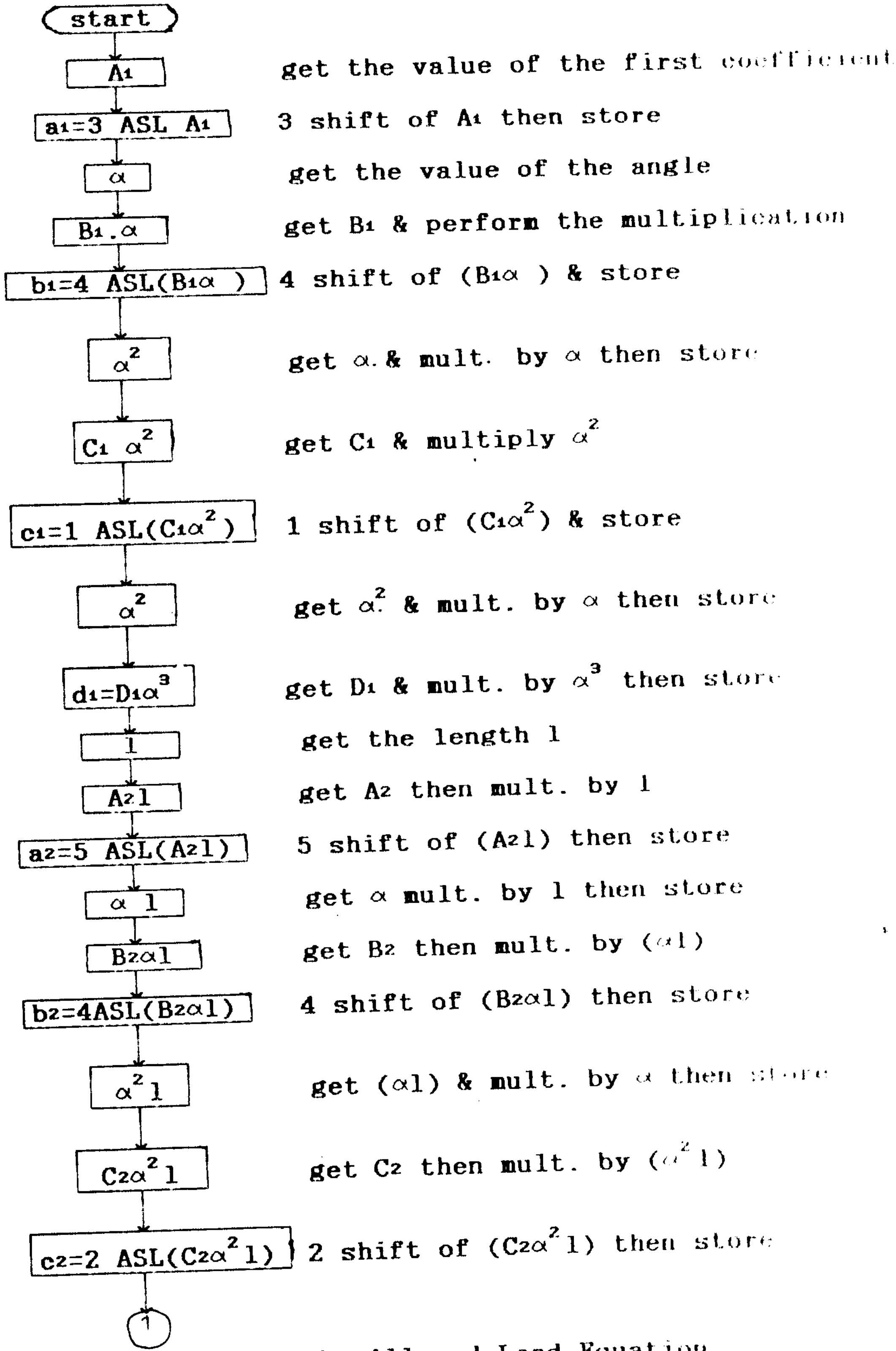


Fig.6.1 Flowchart to Solve the Allowed Load Equation

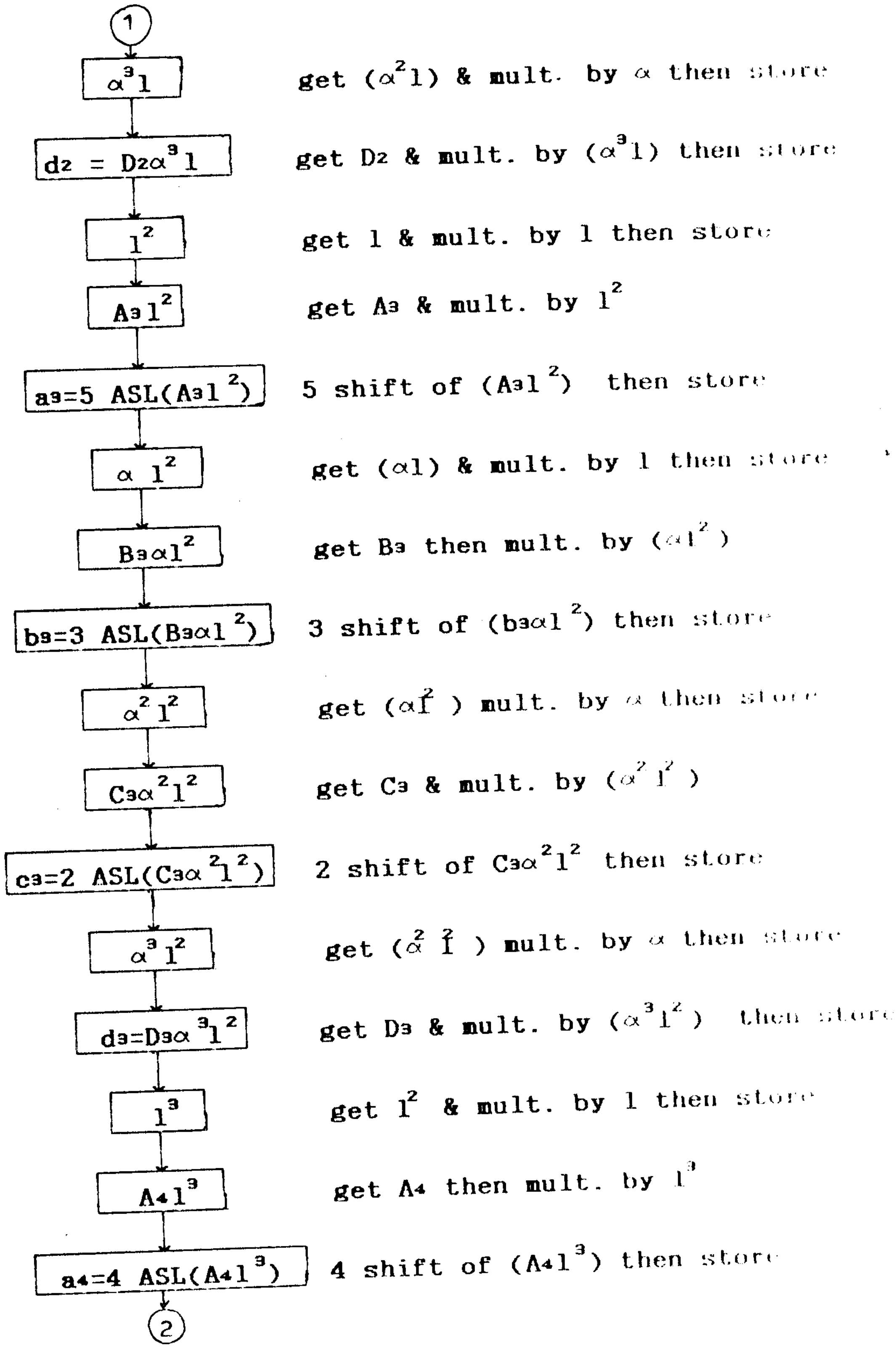


Fig.6.1 Flowchart to Solve the Allowed Load Equation (cont.)

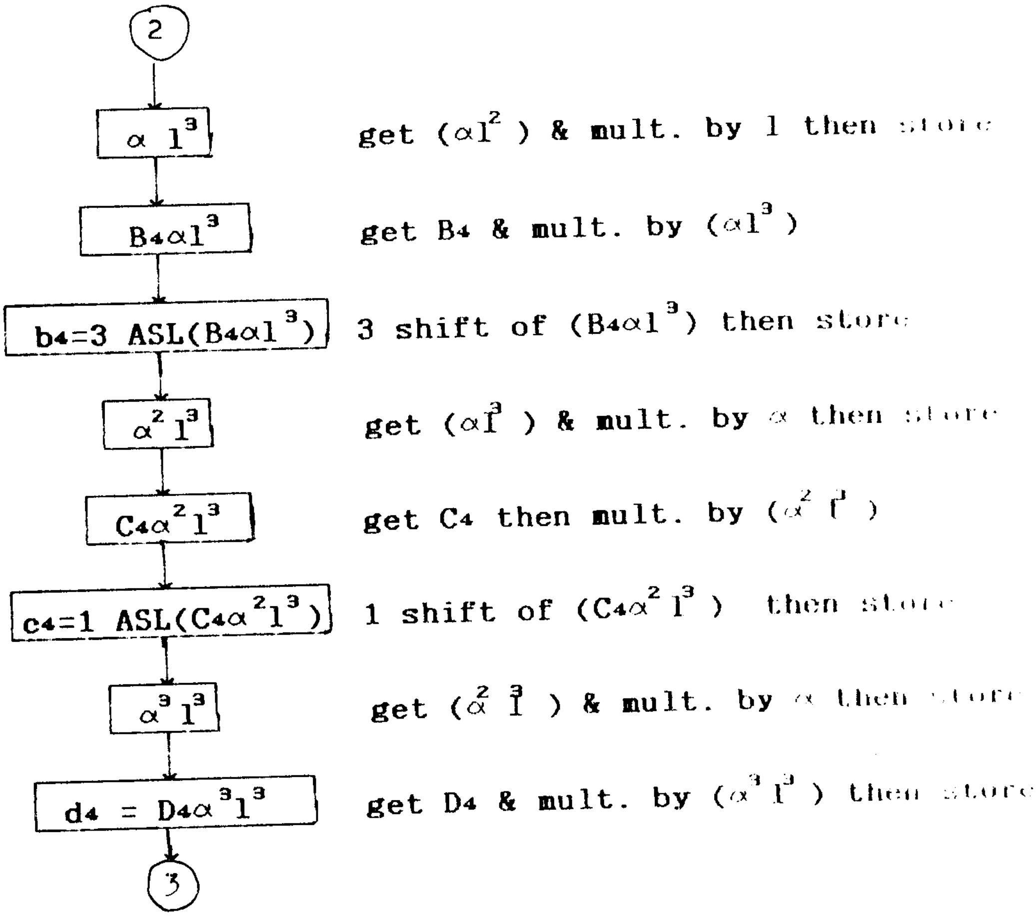


Fig.8.1 Flowchart to solve the Allowed Load Equation (cont.)

At this level the equation changes its form to become as follows

$$A_L(\alpha,L) = \Big[4\ \{(a_1 + c_1)-(b_1 + d_1)\} + 2\ \{(b_2 + d_2)-(a_2 + c_2)\}$$
$$1\ \{(a_3 + c_3)-(b_3 + d_3)\} + \{(b_4 + d_4)-(a_4 + c_4)\}\Big]\ y$$

The continuity of the resolution is as follows:

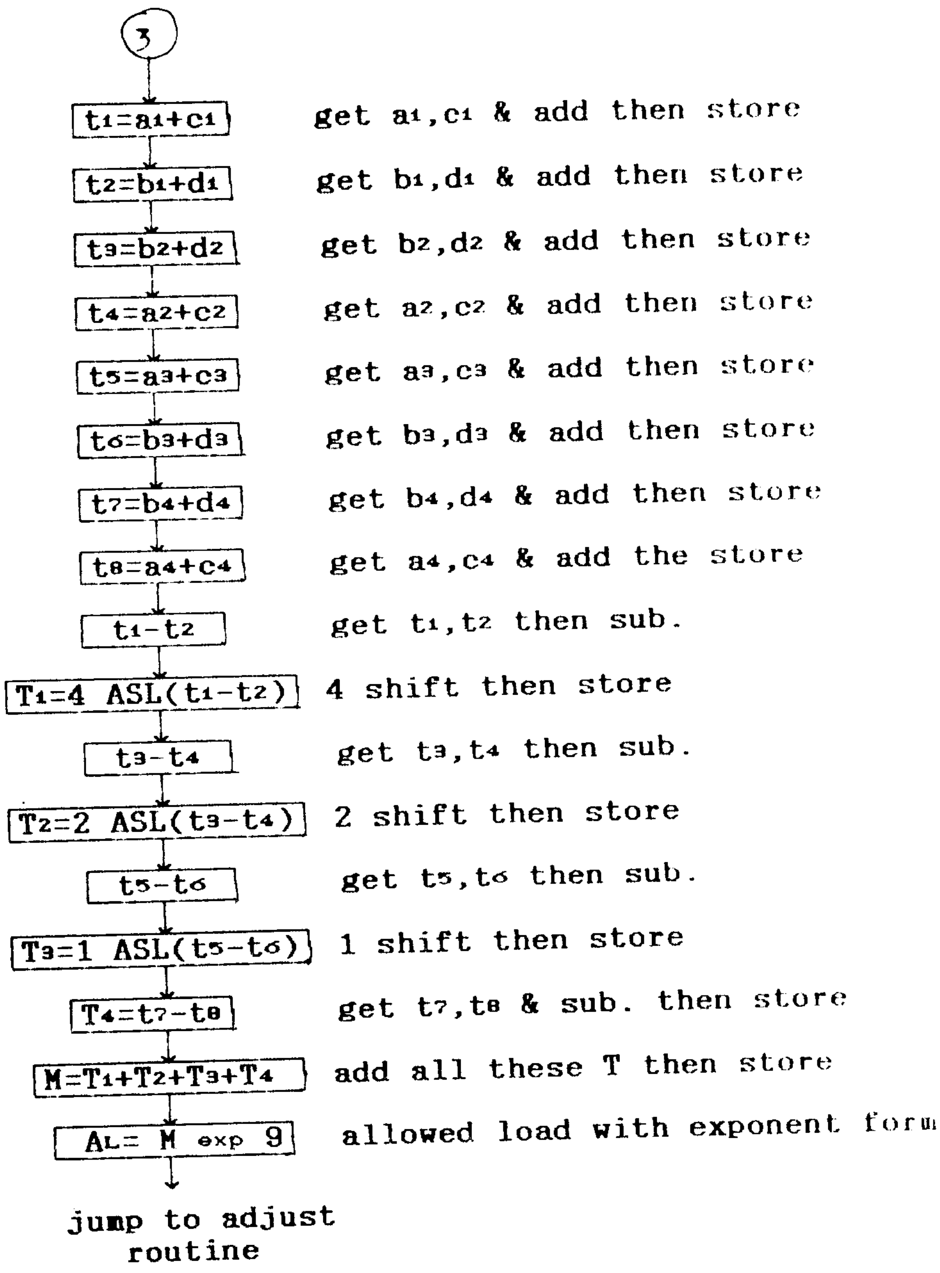


Fig.6.1 Flowchart to Solve the Allowed Load Equation (end)

6.1.3 Resolution Process of the Lifted Load

The following approach is used to solve the lifted load formula given in Eq.1.8. Since that, this equation contains trigonometric terms, first of all, let us demonstrate how this trigonometric terms are solved. The technique adopted is the one which is based on the "look-up table". This table is provided to contain values of the sine function from 0° to 90° as shown in Fig.6.2, of course the same table is used to look for the other trigonometric functions. To find the sine function, the angle itself is used as an address to peek directly the sine value from the table, whereas, for the cosine function, the peeked angle will be subtracted from 90°, then a jump is performed to use again the same routine.

The subroutine for finding the sine, and the cosine functions is called "TRIG" routine, which is shown in Fig.6.3. Notice that, the values of this table are stored in the EPROM as an integer form, without its exponent term, because it is supposed to be automatically (-2) and taken into account in the resolution process.

```
α     --> D0
        BSR      TRIG
        MOVE     D1, <EA>        store sine
        MOVE     #90, A2
        SUB      D0, A2
        MOVE     A2, D0
        BSR      TRIG
        MOVE     D1, <EA>        store cosine

TRIG    MOVE     #F00, A0        A0=F00 is the index table
        LEA      0(A0,D0), A1
        MOVE     A1 , D1
        RTS
```

Fig.6.3 TRIG Routine Program

000F00	sin 0°
000F01	sin 1°
000F02	sin 2°
"	"
"	"
000F5A	sin 89°
000F5B	sin 90°

Fig.6.2 Trigonometric Table

The lifted load equation is given below:

$$M = \frac{P_R S(h\sin\alpha' + O'A\cos\alpha') - (a_1 L + b_1)\sin\alpha}{g\psi\left(L\sin\alpha + e_2\cos\alpha - \frac{e_1}{N}\right)}$$

Based on the constants known as the data crane personality, these constants were given in chapter 4. The constants containing in this equation are:

$S=254469.10^{-7}$, $h=81.10^{-2}$, $O'A=97.10^{-2}$, $a_1=a.10^{-2}$, $b_1=b.10^{-2}$, $g=981.10^{-2}$, $=120.10^{-2}$, $e_1=28.10^{-2}$, $e_2=61.10^{-2}$. Most of these constants have their exponent terms to 10^{-2}. To facilitate the writing let us factorise this equation by putting the exponent as a common factor, thus the lifted load equation will be of the form:

$$M = \frac{P_R S\,10^{-7}(h\sin\alpha' + O'A\cos\alpha')10^{-4} - (aL+b)\sin\alpha\,10^{-4}}{g\psi\,10^{-4}\left(L\sin\alpha + e_2\cos\alpha\,10^{-2} - \frac{e_1}{N}\right)10^{-2}}$$

Simplifying the exponent terms, this equation will be:

$$M = \frac{P_R S\,10^{-7}(h\sin\alpha' + O'A\cos\alpha') - (aL+b)\sin\alpha}{g\psi\left(L\sin\alpha + e_2\cos\alpha\,10^{-2} - \frac{e_1}{N}\right)10^{-2}}$$

Now, let us apply again the same technic as mentioned previously to solve this equation.

$$M = \frac{\left[7P_R S(h\sin\alpha' + O'A\cos\alpha') - (aL+b)\sin\alpha\right]10^{-7}}{g\psi\left[\left(L\sin\alpha - \frac{e_1}{N} + 2e_2\cos\alpha\right)\right]10^{-4}}$$

Finally after simplification the lifted load equation is as follows:

$$M = \frac{\left[7P_R S(h\sin\alpha' + O'A\cos\alpha') - (aL+b)\sin\alpha\right]}{g\psi\left(L\sin\alpha - \frac{e_1}{N} + 2e_2\cos\alpha\right)} 10^{3}$$

This equation is the new form of the lifted load formula, and the algorithm which shows the resolution process is given in Fig.6.4.

6.1.4 Resolution Process Y_0 and Z_0

The free range is given by the Eq.1.10, which can be written as:

$$Y_0 = L\sin\alpha 10^{-2} + e_2\cos\alpha 10^{-4} - O'A 10^{-2}$$

Putting 10^{-2} as a common factor then applying the same procedure. Thus, the free range will be of the form:

$$Y_0 = \left[L\sin\alpha - O'A + 2e_2\cos\alpha\right]10^{-4}$$

The algorithm in Fig.6.5 shows the resolution process of the free range.

The height is given by the Eq.1.9, this equation can be written as:

$$Z_0 = L\cos\alpha 10^{-2} - e_2\sin\alpha 10^{-4} + h 10^{-2}$$

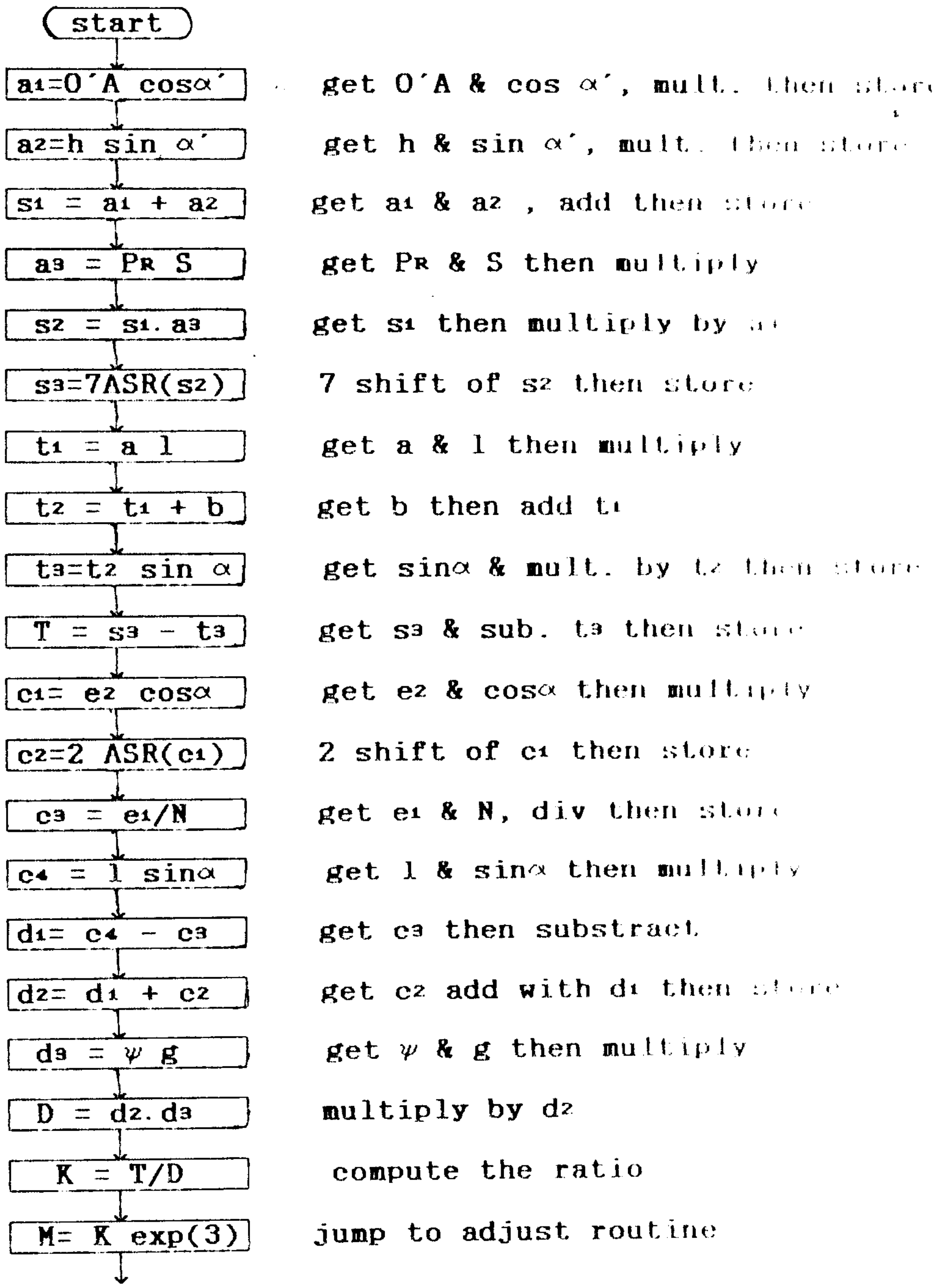


Fig.6.4 Flowchart to solve the Lifted Load Equation

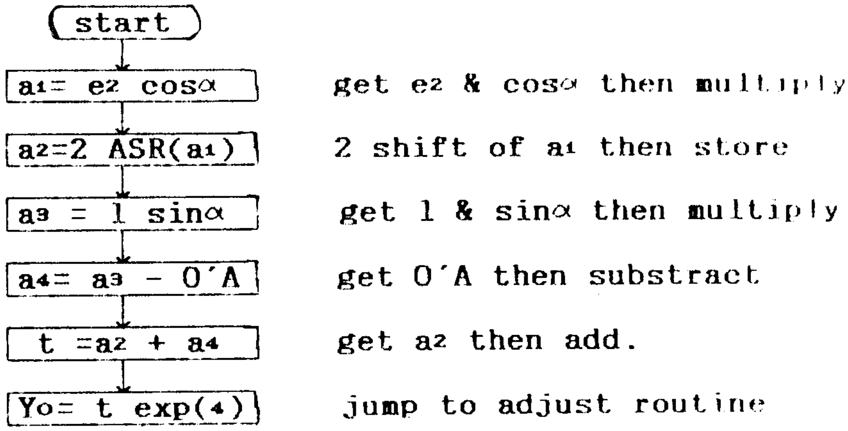


Fig.6.5 Flowchart to solve the Free Range

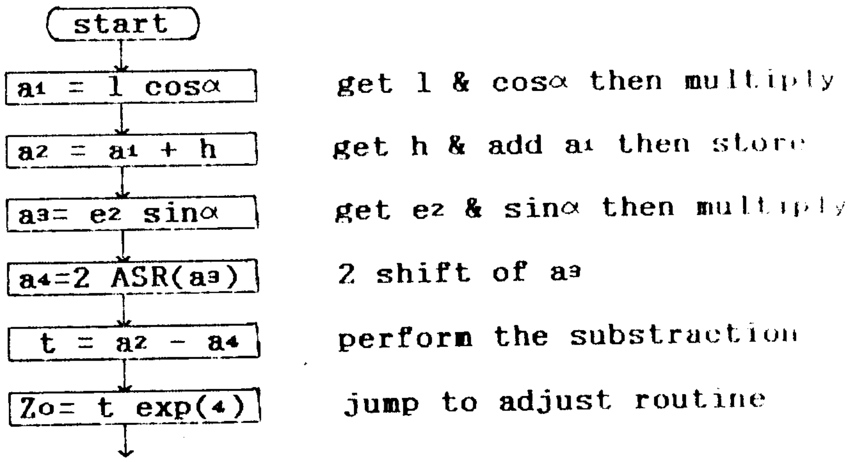


Fig.6.6 Flowchart to solve the Height

Putting 10^{-2} as a common factor then applying the [illegible] procedure as developed previously. Thus, the height will [illegible] of the form:

$$Z_0 = [L\cos\alpha - 2e_2\sin\alpha + h]10^{-2}$$

The algorithm in Fig.6.6 shows the resolution process of [illegible] height.

6.2 MAIN SOFTWARE ROUTINE

Figure 6.7 shows the flowchart of the main [illegible] monitoring program segment. It illustrates the different steps, where the first one concerns the [illegible] initialization. It starts by clearing both the [illegible] registers from A_1 through A_7 and the data registers from [illegible] through D_7. It sets the user stack register (USR) and [illegible] supervisor stack register (SSR). Then it clears all [illegible] peripheral such as the digital and analog display, [illegible] configuration, all the latches and so on. After [illegible] initialization, the CPU generates a dummy address to [illegible] the configuration which is determined by a sequential [illegible] routine. The CPU reads the coefficients of [illegible] corresponding to the configuration. It sets the counter [illegible] 1, then the CPU generates a dummy address to convert [illegible] first input variable. A delay routine is used to wait [illegible] CPU interruption, when it occurs, the software control [illegible] to read the conversion and store the value. A test is [illegible] to check if the conversion of three variable inputs is [illegible] or not. When the data are available, the system software jumps to the allowed load computation subroutine, then to the lifted load computation subroutine and finally to the ratio computation subroutine. This ratio is displayed to the analog display and compared to the value 1. The overload [illegible] is declared when the ratio is greater then 1, by energizing [illegible] the oil-pump relay. Otherwise, a jump is performed to compute the free range, the height and display the corresponding values depending on the preselected configuration.

6.3 EXCEPTION VECTOR

The MC 68000 system has defined the concept of exception processing. Exception processing is similar to what is more generally known as interrupt processing. The exception mechanism allows the 68000 to respond quickly to special internal or external events. The main program is terminated and a context switch is initiated to a new program environment. This new program environment, the exception service routine, is a segment of a program designed to service the requesting condition. The use of the interrupt mechanism may be generalized to handle a wide range of conditions in a microprocessor-based system. In case of an error occurrence, due mainly to circuit hardware or software faults, the mechanism used to stop the execution of a program and to transfer control to a system routine to handle this error is called the exception mechanism.

6.3.1 Exception Vector Table

Each of the exception functions that is performed by the 68000 has a number called the vector number assigned to it. For external interrupts, the interrupting device supplies the vector number of the 68000. On the other hand, for other types of interruptions, the vector number is generated within the microprocessor. The 68000 converts the vector number to the address of corresponding long word storage location in memory. The exception vector table is a sequence of numbers that occupies 1024 bytes (512 sixteen-bit words) of memory. This table occupies memory address 000000 through $0003FF_{16}$. The table is organized as 512 2-word vectors. Each vector is a 32-bit address which will be loaded into the program counter as part of the exception processing sequence. It defines the starting point of the service routine in the program storage memory. Figure [illegible] shows the format in which the address vector is stored in memory.

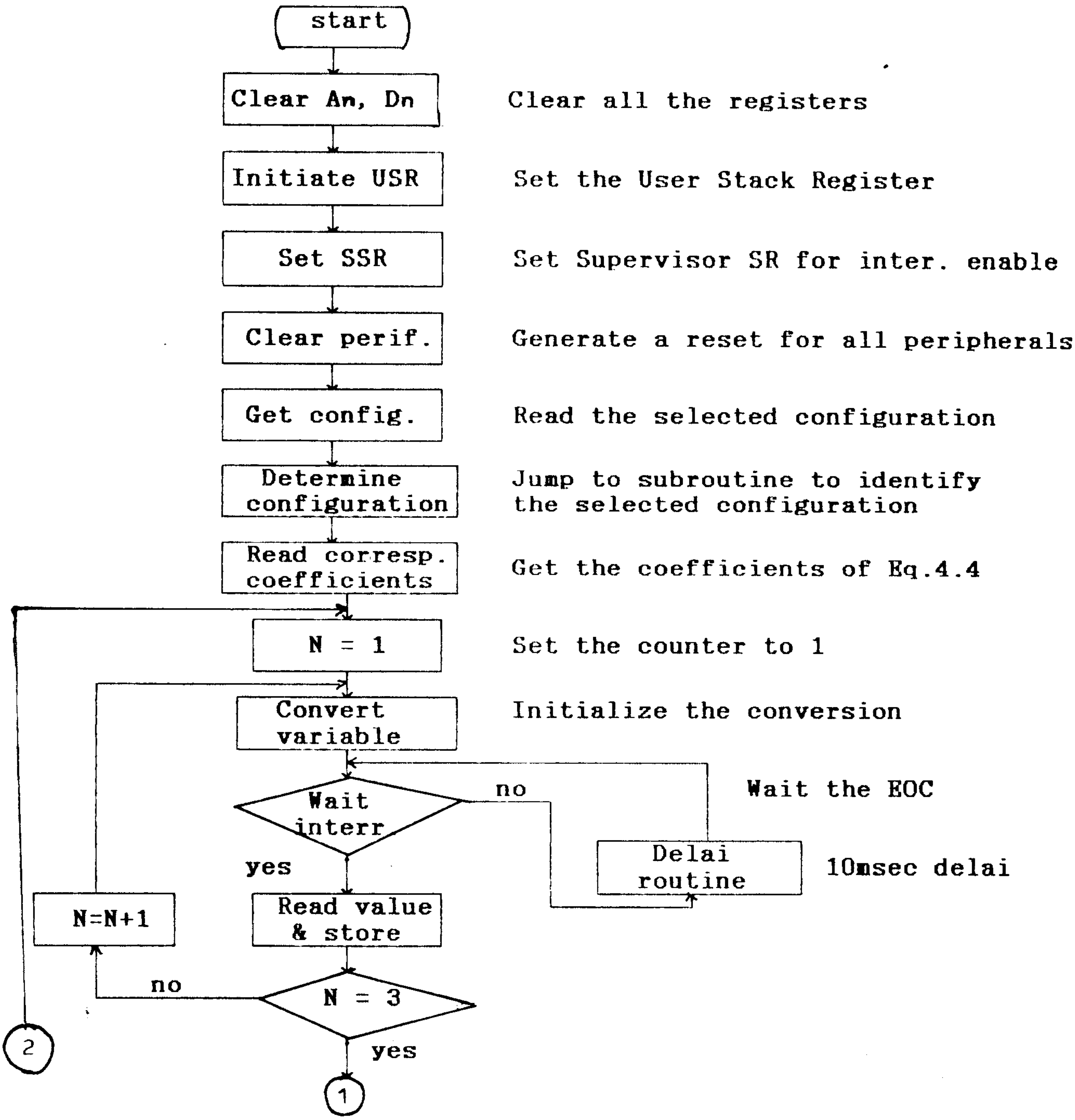


Fig.6.7 Main program (cont.)

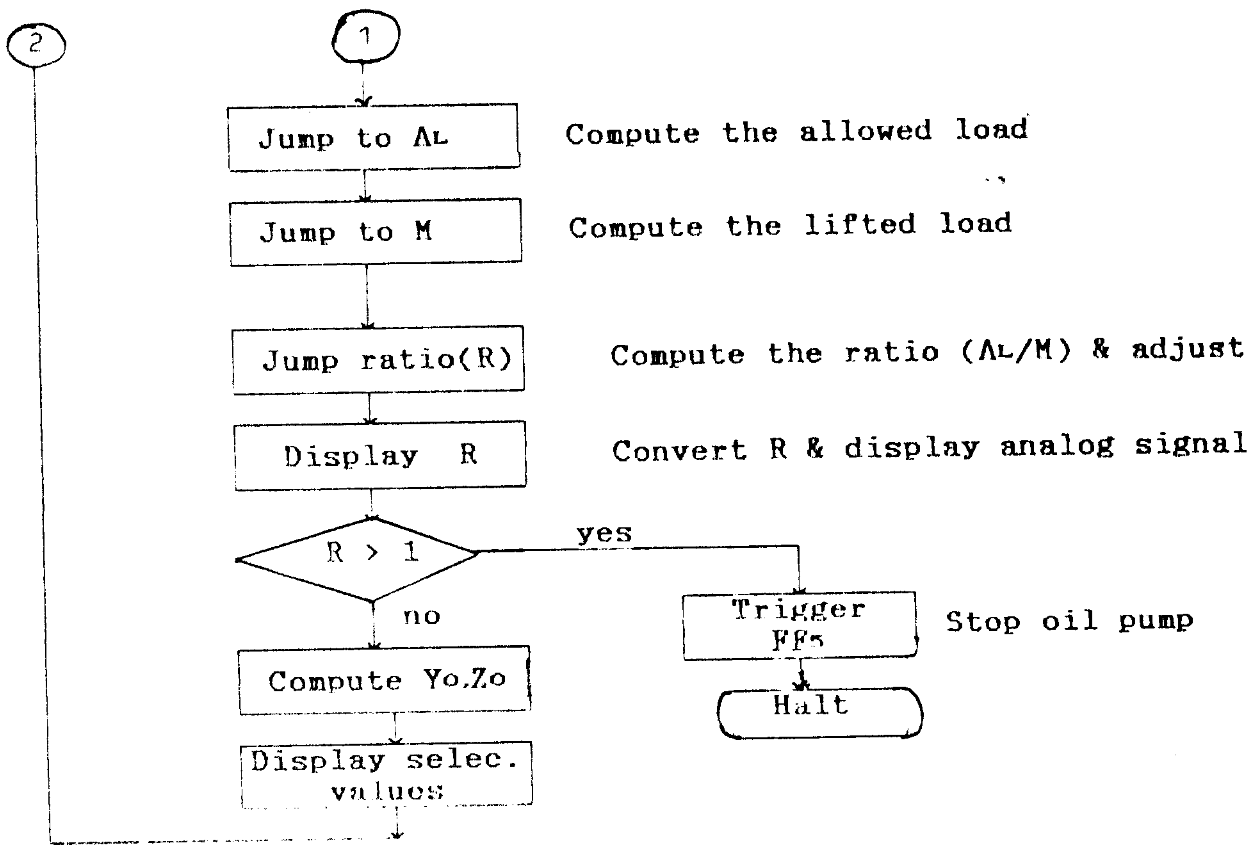


Fig.6.7 Main program (end)

Vector address (Hex)		Vector number
00	RESET SSP	0
04	RESET PC	1
08	Bus Error	2
0C	Ilegal Address	3
10	Ilegal Instruction	4
14	Divide by Zero	5
18	CHK Instruction	6
1C	TRAPV Violation	7
20	Privilege Violation	8
64	Level 1 autovector	19
68	Level 2 autovector	1A
6C	Level 3 autovector	1B
70	Level 4 autovector	1C
74	Level 5 autovector	1D
78	Level 6 autovector	1E
7C	Level 7 autovector	1F
80	Trap instructions	20
100 3FC	User interrupts	40 FF

Fig.6.8 Exception vector address assignments.

CHAPTER 7

CONCLUSION

CHAPTER 7

7.1 CONCLUSION

The investigated work was divided into two parts. The first part, concerns the crane mechanical analysis. The determination of the allowed load requires the deep understanding of the mechanical theory and the rules, especially those related to the norms DIN, that are applied to this crane type. It is one of the reasons that obliges us to find another way of determining the allowed load without going through the long and complex mechanics theory. The solution was to use the multi-nonlinear regression approximation, the results were in good agreement with the data provided by the manufacturer. Thus, the determination of the allowed load is by computation, unlike the conventional microprocessor-based crane load state monitoring systems, where the allowed load values are stored in memories. On the other hand, the proposed crane mechanical analysis, based on three transducers, allows the determination of the lifted load. The accuracy of all the results depends mainly on the precision of both the transducers and the analog-to-digital converter.

The second part deals with the system electronics, where a special attention was taken to minimize the hardware. A minimum basic system was built according to the manufacturer requirements. It offers a large spectrum of facilities, more informative and easily installed. The objective of keeping a basic system hardware is to be able to compare the system fabricated by MORGANITE Company where the unit cost is around 50000 FF. The proposed system electronics cost is estimated to 1000 FF. Notice that this estimation takes into account only the hardware circuit without including the engineering fees and the cost of the development work. This price is determined on the basis of retail prices of a second hand dealer [5].

7.2 SUGGESTED POINTS FOR FURTHER WORK

The system electronics was developed in accordance with the manufacturer requirements and the crane peculiarities. The ENMTP-CPG manufacturer fabricates two other crane types. In order to increase system electronics flexibility so that it can be easily adapted to suit the requirements of other crane types without any modification of the system hardware, we suggest the following points for further work:

1- Study carefully the manufacturer requirements for each crane type.

2- Study the mechanical analysis to determine the lifted load according to the mechanical rules (norm DIN).

3- Based on the load tables provided by the manufacturer, use a third order multi-nonlinear regression method, to determine the allowed load.

4- Check each approximation by computing and plotting the relative errors with respect to both variables length (L) and angle (α).

5- Based on the binary coded decimal (BCD) solution, solve all the derived equations which are the lifted load, the allowed load, the free range and the height.

6- Keep the common software features for all crane types, such as display subroutine and interrupt vectors, including other interrupt sources at the same address locations.

All these steps will simplify the system standardization. Going from one crane type to another will be achieved simply by replacing the appropriate EPROMs containing the software feature of the crane type.

The introduction of the microprocessor in the system design will considerably reduce the total number of the hardware components used. Controlling this standard hardware are different basic software routine for the various crane types. This system standardization also results in a reduction in the time and cost of engineering a new system to suit an entirely different crane model.

Another point may be mentioned is, once we have designed such a monitoring system, it will be possible to think about taking action (control) according to the real-time crane status.

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APPENDIX A

MANUFACTURER DATA

Remarques relatives aux tableaux des charges

- Les portées indiquées sont calculées à partir de l'axe de la couronne d'orientation. Il est tenu compte de la flexion exercée sur la flèche par son propre poids et le poids de la charge nominale.
- Pour le travail en rotation sur 360°, la suspension des essieux AV doit être bloquée hydrauliquement. Pour obtenir une stabilité optimale, les roues de ces essieux doivent affleurer le sol et n'y exercer qu'une légère pression.
- Des positions de flèche autres que celles indiquées aux tableaux des charges ne sont pas admises.

Il y a danger de renversement

- Lorsque la grue étant sur pneus, on fait pivoter la partie tournante en dehors de l'axe longitudinal du véhicule;
- Lorsque les charges et portées indiquées aux tableaux des charges pour la longueur de flèche utilisée sont dépassées;
- Lorsque la grue n'est pas bien d'aplomb sur ses quatre appuis hydraulique. (Essieux AV bloqués, pneus intercalés);
- Lorsque les supports hydrauliques ne reposent pas sur des cales telles que la nature du sol l'exige;
- Lorsqu' à la suite de manœvres inadéquatés, un balancement a été imprimé à la charge suspendue;
- Lorsqu'en état de montage "grue sur pneus" la pression des pneus n'est pas de 10 bars;
- Lorsqu'en état de montage "grue sur pneus" les essieux ne sont pas bloqués.
- Lorsqu'en état de montage "grue sur pneus" les versus de stabilisation ne sont pas sortis. L'écart entre les semelles et la chaussée doit être de 10 cm environ.

Le mécanisme de levage

est conçu pour un effort au brin maximal de 39,2 kN. Cet effort au brin ne doit pas être dépassé et conditionne le câblage de levage nécessaire.
Le poids de l'organe de préhension doit être déduit des charges indiquées.

- moufle de 35 t – poids mort: 300 kg
- moufle de 12 t – poids mort: 145 kg

La flèche télescopique

a une capacité de charge limitée. Les charges indiquées aux tableaux ne doivent pas être dépassées.
Il faut respecter les indications des charges relatives aux éléments de la flèche télescopique à coulissement hydraulique.
Normalement la flèche doit être d'abord sortie jusqu'à la longueur souhaitée pour ne lever la charge qu' ensuite.
La flèche peut être sortie en charge partielle. La charge est fonction de la portée atteinte lorque la flèche est sortie.
Si on télescope en charge, la charge maximale jusqu'à une longueur de flèche de 17,9 m s'élève à 20 t, jusqu'à une longueur de flèche de 23,9 m à 14 t, et jusqu'à 30 m de 10 t. Toutefois, les charges indiquées aux tableaux des charges en fonction des portées ne doivent pas être dépassées.

*

portée [m]   charge [t]
2,2   40
3,4   32,4

Angle (°)	Portée (m)	Hauteur (m)	75 % Force (t)
* 20	3,0	11,7	35,0
× 22,5	3,4	11,4	32,0
25	3,8	11,2	29,7
27,5	4,2	10,9	27,5
30	4,6	10,7	25,8
32,5	5,0	10,4	24,2
35	5,4	10,1	22,9
37,5	5,9	9,7	21,2
40	6,3	9,4	19,9
42,5	6,6	9,0	18,9
45	6,9	8,7	18,0
47,5	7,2	8,3	17,1
50	7,5	7,9	16,2
52,5	7,8	7,4	15,3
55	8,1	7,0	14,5
57,5	8,4	6,6	13,7
60	8,6	6,1	13,1
62,5	8,8	5,6	12,6
65	8,9	5,2	12,3

Tableau des forces de levage 1035

Longueur de flèche : 11,9 m - télescopes complètement rentrés

Etat de montage : grue calée, sur 360°

Câblage de levage : 9 brins

Contrepoids : 5,5 t

° Angle formé par la flèche avec la verticale

m Portée en mètres

m Hauteur de levage en mètres

75 % t Force de levage en tonnes

75 % de l'effort de renversement

Tableau des forces de levage 1035

Longueur de flèche : 17,9 m - télescopes sortis d'un tiers

Etage de montage : grue calée, sur 360°

Câblage de levage : 5 brins

Contrepoids : 5,5 t

°	m	m	75 % t
15	3,2	17,9	19,7
17,5	4,1	17,7	18,3
20	4,8	17,4	17,3
22,5	5,6	17,1	16,1
25	6,3	16,8	15,0
27,5	6,9	16,4	14,2
30	7,6	16,0	13,2
32,5	8,3	15,6	12,3
35	8,9	15,1	11,5
37,5	9,6	14,6	10,6
40	10,3	14,1	9,6
42,5	10,8	13,6	9,0
45	11,4	13,0	8,2
47,5	11,8	12,5	7,8
50	12,4	11,8	7,2
52,5	12,7	11,2	6,9
55	13,2	10,6	6,5
57,5	13,5	9,9	6,2
60	13,7	9,2	6,0
62,5	14,1	8,5	5,7
65	14,4	7,8	5,4

° Angle formé par la flèche avec la verticale

m Portée en mètres

m Hauteur de levage en mètres

75 % t Force de levage en tonnes

75 % de l'effort de renversement

Tableau des forces de levage 1035

Longueur de flèche : 23,9 m - télescopes sortis 2/3

Etat de montage : grue calée, sur 360°

Câblage de levage : 4 brins

Contrepoids : 5,5 t

°	m	m	75 % t
12,5	4,6	24,1	13,4
15	5,5	23,8	12,4
17,5	6,5	23,5	11,4
20	7,4	23,1	10,6
22,5	8,4	22,7	9,7
25	9,3	22,3	8,9
27,5	10,3	21,8	8,2
30	11,0	21,2	7,7
32,5	11,9	20,7	7,2
35	12,6	20,1	6,7
37,5	13,4	19,4	6,2
40	14,1	18,8	5,9
42,5	14,9	18,1	5,4
45	15,5	17,3	5,0
47,5	16,2	16,5	4,7
50	17,0	15,7	4,3
52,5	17,5	14,9	4,1
55	18,3	14,0	3,8
57,5	18,8	13,2	3,6
60	19,2	12,2	3,4
62,5	19,6	11,3	3,3
65	19,9	10,4	3,2

° — Angle formé par la flèche avec la verticale

m — Portée en mètres

m — Hauteur de levage en mètres

75 % t — Force de levage en tonnes*

75 % de l'effort de renversement

Tableau des forces de levage 1035

Longueur de flèche : 30 m - tous télescopes complètement sortis

Etat de montage : grue calée, sur 360°

Câblage de levage : 3 brins

Contrepoids : 5,5 t

°	m	m	75 % t
10	5,0	20,2	10,0
12,5	6,2	29,9	9,1
15	7,5	29,6	8,3
17,5	8,7	29,2	7,6
20	10,1	28,8	6,8
22,5	11,1	28,3	6,4
25	12,3	27,7	5,8
27,5	13,6	27,1	5,4
30	14,5	26,5	5,0
32,5	15,6	25,8	4,7
35	17,1	25,0	4,2
37,5	17,9	24,2	3,9
40	18,8	23,4	3,6
42,5	19,5	22,5	3,4
45	20,4	21,6	3,1
47,5	21,3	20,6	2,8
50	22,1	19,6	2,6
52,5	22,8	18,6	2,4
55	23,5	17,5	2,3
57,5	24,2	16,4	2,2
60	24,8	15,3	2,1
62,5	25,3	14,1	2,0
65	25,9	12,9	1,9

° Angle formé par la flèche avec la verticale

m Portée en mètres

m Hauteur de levage en mètres

75 % t Force de levage en tonnes

75 % de l'effort de renversem

°	m	m	75 % t
20	3,0	11,7	21,0
22,5	3,4	11,4	17,3
25	3,8	11,2	15,0
27,5	4,2	10,9	13,4
30	4,6	10,7	12,0
32,5	5,0	10,4	10,7
35	5,4	10,1	9,7
37,5	5,9	9,7	8,7
40	6,3	9,4	7,8
42,5	6,6	9,0	7,4
45	6,9	8,7	6,9
47,5	7,2	8,3	6,6
50	7,5	7,9	6,1
52,5	7,8	7,4	5,7
55	8,1	7,0	5,4
57,5	8,4	6,6	5,1
60	8,6	6,1	4,9
62,5	8,8	5,6	4,7
65	8,9	5,2	4,6

° — Angle formé par la flèche avec la verticale

m — Portée en mètres

m — Hauteur de levage en mètres

75 % t — Force de levage en tonnes

75 % de l'effort de renversement

Tableau des forces de levage 1035

Longueur de flèche : 11,9 m - tous télescopes complètement rentrés

Etat de montage : grue sur pneus - orientable vers l' arrière

Câblage de levage : ~ 9 brins

Contrepoids : ~ 5,5 t

Tableau des forces de levage 1035

Longueur de flèche : 17,9 m - télescopes sortis d'un tiers

Etat de montage : grue sur pneus - orientable vers l'arrière

Câblage de levage : 5 brins

Contrepoids : 5,5 t

o	m	m	75 % t
17,5	4,1	17,7	13,2
20	4,8	17,4	10,8
22,5	5,6	17,1	9,0
25	6,3	16,8	7,8
27,5	6,9	16,4	7,0
30	7,6	16,0	6,2
32,5	8,3	15,6	5,5
35	8,9	15,1	5,0
37,5	9,6	14,6	4,5
40	10,3	14,1	4,0
42,5	10,8	13,6	3,7
45	11,4	13,0	3,3
47,5	11,8	12,5	3,1
50	12,4	11,8	2,9
52,5	12,7	11,2	2,7
55	13,2	10,6	2,5
57,5	13,5	9,9	2,4
60	13,7	9,2	2,3

o — Angle formé par la flèche avec la verticale

m — Portée en mètres

m — Hauteur de levage en mètres

75 % t — Force de levage en tonnes

75 % de l'effort de renversement

Portée[m] Charge[T]
2,8 40
3,4 32,4

°	m	m	75 % t
20	3	11,7	35
22,5	3,4	11,4	32
25	3,8	11,2	29,6
27,5	4,2	10,9	27,6
30	4,6	10,7	25,6
32,5	5	10,4	23,7
35	5,4	10,1	21,9
37,5	5,9	9,7	19,7
40	6,3	9,4	18,1
42,5	6,6	9	17
45	6,9	8,7	15,7
47,5	7,2	8,3	14,8
50	7,5	7,9	13,8
52,5	7,8	7,4	12,9
55	8,1	7	12,1
57,5	8,4	6,6	11,3
60	8,6	6,1	10,9
62,5	8,8	5,6	10,4
65	8,9	5,2	10,2

° — Angle formé par la flèche avec la verticale

m — Portée en mètres

m — Hauteur de levage en mètres

75 % t — Force de levage en tonnes. 75 % de l'effort de renversement

Tableau des forces de levage 1035

Longueur de flèche	:	11,9 m - télescopes complètement rentrés
Etat de montage	:	grue calée, sur 360°
Câblage de levage	:	9 brins
Contrepoids	:	2 t

Tableau des **forces** de levage 1035

Longueur de flèche : 17,9 m télescope sortis d' un tiers

Etat de montage : grue calée, sur 360°

Câblage de levage : 5 brins

Contrepoids : 2 t

°	m (portée)	m (hauteur)	75 % t
15	3,2	17,9	19,7
17,5	4,1	17,7	18,3
20	4,8	17,4	17,2
22,5	5,6	17,1	16
25	6,3	16,8	15
27,5	6,9	16,4	14
30	7,6	16	12,8
32,5	8,3	15,6	11,6
35	8,9	15,1	10,5
37,5	9,6	14,6	9,3
40	10,3	14,1	8,3
42,5	10,8	13,6	7,7
45	11,4	13	7
47,5	11,8	12,5	6,5
50	12,4	11,8	6
52,5	12,7	11,2	5,7
55	13,2	10,6	5,3
57,5	13,5	9,9	5,1
60	13,7	9,2	4,9
62,5	14,1	8,5	4,6
65	14,4	7,8	4,4

° Angle formé par la flèche avec la verticale

m Portée en mètres

m Hauteur de levage en mètres

75 % t Force de lev... en tonnes

75 % de l'...rt de renvers...

Tableau des forces de levage 1035

Longueur de flèche : 23,9 m - télescopes sortis 2/3

Etat de montage : grue calée, sur 360°

Câblage de levage : 4 brins

Contrepoids : 2 t

°	m	m	75 % t
12,5	4,6	24,1	13,4
15	5,5	23,8	12,4
17,5	6,5	23,5	11,4
20	7,4	23,1	10,5
22,5	8,4	22,7	9,6
25	9,3	22,3	8,7
27,5	10,3	21,8	7,8
30	11	21,2	7,1
32,5	11,9	20,7	6,3
35	12,6	20,1	5,8
37,5	13,4	19,4	5,2
40	14,1	18,8	4,7
42,5	14,9	18,1	4,3
45	15,5	17,3	4
47,5	16,2	16,5	3,7
50	17	15,7	3,4
52,5	17,5	14,9	3,2
55	18,3	14	2,9
57,5	18,8	13,2	2,8
60	19,2	12,2	2,7
62,5	19,6	11,3	2,5
65	19,9	10,4	2,4

° Angle formé par la flèche avec la verticale

m Portée en mètres

m Hauteur de levage en mètres

75 % t Force de levage en tonnes

75 % de l'effort de renversement

ableau des forces de levage 1035

Longueur de flèche : 30 m - tous télescopes complètement sortis

Etat de montage : grue calée, sur 360°

Câblage de levage : 3 brins

Contrepoids : 2 t

°	m	m	75 % t
10	5	30,2	10
12,5	6,2	29,9	9,1
15	7,5	29,6	8,2
17,5	8,7	29,2	7,5
20	10,1	28,8	6,7
22,5	11,1	28,3	6,2
25	12,3	27,7	5,6
27,5	13,6	27,1	5
30	14,5	26,5	4,6
32,5	15,6	25,8	4,1
35	17,1	25	3,5
37,5	17,9	24,2	3,2
40	18,8	23,4	2,9
42,5	19,5	22,5	2,6
45	20,4	21,6	2,4
47,5	21,3	20,6	2,2
50	22,1	19,6	2
52,5	22,8	18,6	1,8
55	23,5	17,5	1,7
57,5	24,2	16,4	1,5
60	24,8	15,3	1,4
62,5	25,3	14,1	1,3
65	25,9	12,9	1,2

° — Angle formé par la flèche avec la verticale

m — Portée en mètres

m — Hauteur de levage en mètres

75 % t — Force de levage en tonnes; 75 % de l'effort de renversement

Traglasttabelle 1035

Auslegerlänge	:	11,9 m - alle Teleskope ganz eingefahren
Rüstzustand	:	freistehend nach hinten
Hubseileinscherung	:	5 strängig
Gegengewicht	:	2 t

Tableau des forces de levage 1035

Longueur de flèche	:	11,9 m - télescopes complètement rentrés
Etat de montage	:	grue sur pneus orientable vers l'arrière
Câblage de levage	:	5 brins
Contrepoids	:	2 t

°	m	m	75 % t
20	3,0	11,7	17,5
22,5	3,4	11,4	14,7
25	3,8	11,2	12,4
27,5	4,2	10,9	11,1
30	4,6	10,7	9,8
32,5	5,0	10,4	8,9
35	5,4	10,1	8,0
37,5	5,9	9,7	7,0
40	6,3	9,4	6,4
42,5	6,6	9,0	6,0
45	6,9	8,7	5,6
47,5	7,2	8,3	5,2
50	7,5	7,9	4,9
52,5	7,8	7,4	4,5
55	8,1	7,0	4,2
57,5	8,4	6,6	3,9
60	8,6	6,1	3,7
62,5	8,8	5,6	3,5
65	8,9	5,2	3,4

° — Winkelstellung des Auslegers zur Senkrechten / Angle formé par la flèche avec la verticale

m — Ausladung in Meter / Portée en mètres

m — Hubhöhe in Meter / Hauteur de levage en mètres

75 % t — Last in Tonnen bei Kipplastausnutzung 75 % / Force de levage en tonnes 75 % de l'effort de renversement

Traglasttabelle 1035

Auslegerlänge	:	17,9 m - Teleskope 1/3 ausgefahren
Rüstzustand	:	freistehend nach hinten
Hubseileinscherung	:	5strängig
Ballast	:	2 t

Tableau des forces 1035

Longueur de flèche	:	17,9 m - télescopes sortis d'un tiers
Etat de montage	:	grue sur pneus - orientable vers l'arrière
Câblage de levage	:	5 brins
Contrepoids	:	2 t

°	m	m	75 % t
15	3,2	17,9	14,0
17,5	4,1	17,7	10,7
20	4,8	17,4	9,0
22,5	5,6	17,1	7,5
25	6,3	16,8	6,5
27,5	6,9	16,4	5,8
30	7,6	16,0	5,1
32,5	8,3	15,6	4,4
35	8,9	15,1	4,0
37,5	9,6	14,6	3,5
40	10,3	14,1	3,0
42,5	10,8	13,6	2,8
45	11,4	13,0	2,4
47,5	11,8	12,5	2,2
50	12,4	11,8	2,0
52,5	12,7	11,2	1,9
55	13,2	10,6	1,7
57,5	13,5	9,9	1,6
60	13,7	9,2	1,5
62,5	14,1	8,5	1,3

° — Winkelstellung des Auslegers zur Senkrechten / Angle formé par la flèche avec la verticale

m — Ausladung in Meter / Portée en mètres

m — Hubhöhe in Meter / Hauteur de levage en mètres

75 % t — Last in Tonnen bei Kipplastausnutzung 75 % / Force de levage en tonnes 75 % de l'effort de renversement

APPENDIX B

APPROXIMATED DATA

TABLEAU DES FORCES DE LEVAGE 1040

Longueur de fleche : 11.9 m - telescope completement rentrees.
Etat de montage : grue calee, sur 360°
Cablage de levage : 9 brins
Contrepoids : 5.5 t

angle/ver.	charge autorisee 75%
20	34.57605
22.5	32.04301
25	29.7335
27.5	27.6331
30	25.72768
32.5	24.0029
35	22.44445
37.5	21.0381
40	19.76954
42.5	18.62457
45	17.58878
47.5	16.64799
50	15.78798
52.5	14.99415
55	14.25268
57.5	13.54896
60	12.86886
62.5	12.19805
65	11.52225

TABLEAU DES FORCES DE LEVAGE 1040

Longueur de fleche : 17.9 m - telescope sortis d'un tiers
Etat de montage : grue calee, sur 360°
Cablage de levage : 5 brins
Contrepoids : 5.5 t

angle/ver.	charge autorisee 75%
15	19.55371
17.5	18.36713
20	17.21939
22.5	16.11229
25	15.0476
27.5	14.02682
30	13.05188
32.5	12.12447
35	11.24624
37.5	10.41902
40	9.644462
42.5	8.924469
45	8.260397
47.5	7.654391
50	7.108094
52.5	6.622725
55	6.200821
57.5	5.843504
60	5.55282
62.5	5.330366
65	5.177866

TABLEAU DES FORCES DE LEVAGE 1040

Longueur de fleche : 23.9 m - telescopes sortis de 2/3
Etat de montage : grue calee, sur 360°
Cablage de levage : 4 brins
Contrepoids : 5.5 t

angle/ver.	charge autorisee 75%
12.5	13.35127
15	12.34957
17.5	11.42052
20	10.56043
22.5	9.765839
25	9.033341
27.5	8.358948
30	7.739179
32.5	7.171318
35	6.650795
37.5	6.174515
40	5.738888
42.5	5.340538
45	4.975296
47.5	4.640465
50	4.332226
52.5	4.046196
55	3.780178
57.5	3.529633
60	3.291569
62.5	3.062142
65	2.837845

TABLEAU DES FORCES DE LEVAGE 1040

Longueur de fleche : 30.0 m - telescope completement sortis
Etat de montage : grue calee, sur 360°
Cablage de levage : 3 brins
Contrepoids : 5.5 t

angle/ver.	charge autorisee 75%
10	9.932556
12.5	9.134994
15	8.399384
17.5	7.722855
20	7.102005
22.5	6.533737
25	6.014992
27.5	5.541886
30	5.111679
32.5	4.72107
35	4.366669
37.5	4.045418
40	3.754089
42.5	3.489685
45	3.24791
47.5	3.026993
50	2.823181
52.5	2.632019
55	2.452263
57.5	2.27919
60	2.110436
62.5	1.942337
65	1.771607

TABLEAU DES FORCES DE LEVAGE 1040

Longueur de fleche : 11.9 m - telescope completement rentres
Etat de montage : grue sur pneu - orientable vers l'arriere
Cablage de levage : 9 brins
Contrepoids : 5.5 t

angle/ver.	charge autorisee 75%
20	20.32073
22.5	17.75926
25	15.53707
27.5	13.62736
30	12.00337
32.5	10.63832
35	9.505398
37.5	8.577842
40	7.8289
42.5	7.23176
45	6.759607
47.5	6.38571
50	6.083299
52.5	5.825559
55	5.585686
57.5	5.336951
60	5.05256
62.5	4.70572
65	4.269686

TABLEAU DES FORCES DE LEVAGE 1040

Longueur de fleche : 17.9 m - telescope sortis d'un tiers
Etat de montage : grue sur pneu - orientable vers l'arriere
Cablage de levage : 5 brins
Contrepoids : 5.5 t

angle/ver.	charge autorisee 75%
15	14.83461
17.5	12.78155
20	10.99822
22.5	9.463671
25	8.157006
27.5	7.057317
30	6.143698
32.5	5.395229
35	4.790982
37.5	4.310077
40	3.931608
42.5	3.634657
45	3.39827
47.5	3.201576
50	3.023688
52.5	2.843668
55	2.640566
57.5	2.393525
60	2.081647

TABLEAU DES FORCES DE LEVAGE 1040

Longueur de fleche : 11.9 m - telescope completement rentres
Etat de montage : grue calee, sur 360°
Cablage de levage : 9 brins
Contrepoids : 2 t

angle/ver.	charge autorisee 75%
20	34.86795
22.5	32.2805
25	29.85409
27.5	27.58537
30	25.47117
32.5	23.50832
35	21.69354
37.5	20.02367
40	18.49548
42.5	17.10576
45	15.85122
47.5	14.72898
50	13.73526
52.5	12.86731
55	12.12173
57.5	11.49528
60	10.98488
62.5	10.5872
65	10.29921

TABLEAU DES FORCES DE LEVAGE 1040

Longueur de fleche : 17.9 m - telescope sortis d'un tiers
Etat de montage : grue calee, sur 360°
Cablage de levage : 5 brins
Contrepoids : 2 t

angle/ver.	charge autorisee 75%
15	19.84892
17.5	18.57579
20	17.3254
22.5	16.10298
25	14.91409
27.5	13.76386
30	12.65767
32.5	11.60092
35	10.59888
37.5	9.656891
40	8.780304
42.5	7.974411
45	7.244557
47.5	6.596392
50	6.034523
52.5	5.564997
55	5.192692
57.5	4.923188
60	4.761714
62.5	4.713638
65	4.784441

TABLEAU DES FORCES DE LEVAGE 1040

Longueur de fleche : 23.9 m - telescope sortis
de 2/3

Etat de montage : grue calee, sur 360°
Cablage de levage : 4 brins
Contrepoids : 2 t

angle/ver.	charge autorisee 75%
12.5	13.7256
15	12.59465
17.5	11.53429
20	10.54271
22.5	9.618065
25	8.758881
27.5	7.963135
30	7.229203
32.5	6.555386
35	5.939919
37.5	5.381001
40	4.876953
42.5	4.425907
45	4.026306
47.5	3.676594
50	3.374226
52.5	3.11845
55	2.906677
57.5	2.737854
60	2.609757
62.5	2.520872
65	2.469652

TABLEAU DES FORCES DE LEVAGE 1040

Longueur de fleche : 30.0 m - telescope completement sortis
Etat de montage : grue calee, sur 360°
Cablage de levage : 3 brins
Contrepoids : 2 t

angle/ver.	charge autorisee 75%
10	10.28415
12.5	9.381516
15	8.539795
17.5	7.75708
20	7.030838
22.5	6.358841
25	5.739121
27.5	5.169045
30	4.64666
32.5	4.169655
35	3.735825
37.5	3.342789
40	2.988449
42.5	2.670288
45	2.386559
47.5	2.134949
50	1.912361
52.5	1.717903
55	1.547928
57.5	1.401474
60	1.275353
62.5	1.167793
65	1.076843

TABLEAU DES FORCES DE LEVAGE 1040

Longueur de fleche : 11.9 m - telescope completement rentres

Etat de montage : grue sur pneus - orientable vers l'arriere

Cablage de levage : 9 brins

Contrepoids : 2 t

angle/ver.	charge autorisee 75%
20	16.98322
22.5	14.79895
25	12.90659
27.5	11.28315
30	9.90535
32.5	8.749786
35	7.793495
37.5	7.013069
40	6.385239
42.5	5.88691
45	5.494599
47.5	5.185272
50	4.935532
52.5	4.722191
55	4.521927
57.5	4.311585
60	4.068009
62.5	3.767601
65	3.387688

TABLEAU DES FORCES DE LEVAGE 1040

Longueur de fleche : 17.9 m - telescope sortis d'un tiers
Etat de montage : grue sur pheus - orientable vers l'arriere
Cablage de levage : 5 brins
Contrepoids : 2 t

angle/ver.	charge autorisee 75%
15	13.09567
17.5	11.116
20	9.406311
22.5	7.945313
25	6.711914
27.5	5.685211
30	4.844422
32.5	4.168488
35	3.636841
37.5	3.228333
40	2.921845
42.5	2.69693
45	2.532288
47.5	2.407349
50	2.300781
52.5	2.191742
55	2.059692
57.5	1.88324
60	1.641876
62.5	1.314209