THE UNIVERSITY OF MANITOBA

THE APPLICATION OF COMMERCIAL FORCE CONTROL GAUGES FOR PROPORTIONING FEED RATION INGREDIENTS FOR ON-FARM FEED MIXING

by

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ABSTRACT

THE APPLICATION OF COMMERCIAL FORCE CONTROL GAUGES FOR PROPORTIONING FEED RATION INGREDIENTS FOR ON-FARM FEED MIXING

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This research was conducted to determine the feasibility of using commercial force control gauges to automatically proportion feed ration ingredients on a mass basis. Wheat was used to simulate different ingredients. The control was sequential control through the activating of microswitches mounted on the tension force control device.

The microswitches were connected to magnetic relays on a control panel to start or stop motors which were used on augers to deliver the various ingredients to the batching hopper. A ring dynamometer was used as a secondary standard to determine the amount of each ingredient delivered by the individual augers. Static calibration of the ring dynamometer was used during the period of testing.

The precision of the tension force control device when the target desired ingredient amounts were 100, 200, 300, 500 and 700 kg was better than 3 percent but the accuracies at each desired ingredient amount were only 18, 13, 4.1, 2.7 and 2.0 percent, respectively. The accuracy of the microswitch settings for the desired total cumulative amount of 1000 kg was 2.0 percent. The ingredient amounts

obtained at $-20^{\circ}C$ differed from the ingredient amounts obtained at $20^{\circ}C$ by -1.3, 0.92 and 1.9 percent when the desired ingredient amounts were 500, 300 and 200 kg respectively. At $40^{\circ}C$ the differences were 0.57, -1.6 and 0.25 percent, respectively compared to the ingredient amount at $20^{\circ}C$.

The compression force control device was used to simulate a grinder-mixer hopper load to determine the effect of off-center loading. Three positions for the loading were investigated. The precisions of microswitch activation were better than 5 percent when the imposed loads were 96.0, 192, 478 and 955 kg. The accuracies were 9.1, 5.1, 2.2 and 1.4 percent, respectively. Off-center loading gave greatly reduced accuracy for the indicated amounts compared to actual hopper loads. When the applied load was only 20 percent of span length off center, the error was 43 percent.

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CHAPTER I

INTRODUCTION

The rapid rate of technological progress in the farm sector in Canada over the past twenty years has greatly increased the productivity of agriculture. The average Canadian farmer can now produce enough food for about 58 people. The labor requirements for some farm operations can be provided for by automation. Automation can keep the production costs at a level which will permit a reasonable return on investment.

The need for an accurate farm weighing system arises basically from the need to increase mechanization and to optimize production. Accurate weighing could help farmers in the following ways:

1. Feed ration ingredients could be more accurately proportioned for balanced rations.

2. The mixed feed ration could be more accurately metered to the livestock.

3. Record keeping could be more accurate so that operators will be more aware of profit margins.

4. Decisions could be made based on the actual weights of animals and feed.

Feed costs for animal production represent from 50 to 75 percent of the production costs for meat, milk and eggs. Many studies have been reported on the improvement of the energy content of feed and methods of feeding animals economically.

Interest has developed in grouping cows and feeding each group a ration to satisfy the nutritional requirements for the group. Herds are divided into groups mainly according to stage of lactation, age and temperament. The advantage of grouping is that it enables each group to be fed a different ration. Farmers need a reliable method of weighing at least a representative number of livestock once every two weeks. By check weighing each animal a farmer could detect which animals are not making good gains.

Weighing equipment for both animal weighing and feed weighing should be very reliable with low maintenance requirements. An automatic system would be desirable for ration ingredient proportioning.

Electronic load cells with an indicator or a recorder have been widely used to weigh bulk grain and animals and to automatically proportion feed. These load cells have been found to be accurate. The system must be zeroed or balanced each time before weighing. Faulty load cells or electronic components are expensive to replace and often must be returned to the manufacturer for repair. Batch weighing with a beam scale or a dial scale provides a continuous weight reading but requires labor to operate, read and record the weight as indicated.

The general purpose of this research was to determine the feasibility of using commercial force control switches to weigh and control the weight of feed ingredients for animal rations. The specific objectives of this research were:

1. To design and develop an automatic feed ingredient weighing system utilizing commercial force control switches.

2. To test the developed system for accuracy and precision for various rations and under different temperature conditions.

CHAPTER II

REVIEW OF LITERATURE

2.1 Automatic control of feed preparation

Canada is one of the largest grain producers in the world with annual production exceeding 30 million tonnes. Almost half of this is exported and the remainder is used for human food and animal feed (Canadian International Grain Institute, 1975). Oats and barley are used primarily in cattle feeds whereas wheat and corn are more suitable for poultry and hogs. Corn and soybean meal (a by-product of the soybean oil industry) are widely available in the U.S. for livestock feeding purposes.

The use of grain grown specifically for animal feed has been developed during the last century. Research has resulted in detailed information concerning the nutritional requirements for animal growth. The grains most widely used have been oats, barley and wheat. Soybean meal now serves as the principal source of protein and in the U.S. corn is the principal source of energy. Alternatively, other feed grains are regarded as energy sources if they are economically competitive with corn.

Rations for animals must be tailored to their requirementsand will vary considerably depending on the weight and age of the animal and the rate of growth. The right quantity of feed must then be metered for each animal or group of animals. Bath (1970) reported that cows on complete rations produced 6.8 percent more milk per day than cows fed incomplete rations.

Animal rations are specified and mixed by weight rather than by volume (Hephard, 1973). The disadvantages of measuring feed by volume are: 1. The variation in bulk density between batches of feed will affect the final weight. 2. Manual leveling of the ingredients is required so as to align the calibration marks. 3. When several grains are used in the ration, a corresponding number of calibrations are required. This can be confusing.

Ration preparation often directly relates to the type of feeding mechanism or feeding practices. Feed metering equipment with an accuracy of $\pm$ 5 percent is considered acceptable. Pneumatic controlled dispensers have been reported by Hephard (1973). The system consisted of a small compressor for compressed air and pneumatic valves. The advantage of pneumatic systems over electrical systems was in terms of reliability under the relatively dusty, hot and humid conditions associated with feed handling.

Livestock farming usually requires the preparation of numerous types of rations. An important aspect of feed preparation is quality control. The multiplicity of ingredients and the specific requirements of each feed ration increase the possibility of errors. The conventional method of preparing rations is to use a batch type mixer. When several different ingredients are used a higher labor input is required. The working conditions are usually unattractive to skilled workers who can accurately prepare rations (Reece, 1974). Thus, an automatically controlled feedmill with a minimum of labor input is desirable.

Daum and Puckett (1966) successfully accomplished automatic proportioning of concentrate and roughage by regulating the output of a silo unloader in proportion to the amount of concentrate delivered at a constant rate. This system was successful with a top unloading silo but was unsuitable for some bottom unloading silos because their delivery was unsteady and very difficult to regulate. Hyde (1970) developed an automatic control system for proportioning feed concentrate by volume. This system would proportion the concentrate to roughages drawn from different sources. The device used for sensing the roughage flow rate was a commercially available roughage weigher consisting of a constant speed conveyor supported on a pivot at one end and on a differential transformer loadcell at the other end.

Conveyor belt weighing systems use a precision loadcell assembly and a control system (i.e. control console) to display and record the flow rate and the total accumulated feed. The loadcells are hermetically sealed and transmit signals to the control console. The signal is displayed on the flow rate indicator and recorded on a strip chart. The signal is also integrated to provide the total amount delivered. The system can be programmed for a desired amount to be delivered (Weigh Systems Inc. Bulletin). This system of feed proportioning is widely used in commercial feed manufacturing.

2.2 Typical weighing instruments for feed preparation

The need for the development and installation of forage and grain metering equipment that will provide for good records to assist in better management is important (McFate and George, 1968). Numerous feed metering and weighing devices are available and have been used in feed proportioning systems. To detect poorly proportioned rations, feed records and related information for calculating costs at regular intervals should be available to the farmer. Metering units to control the ration have the greatest effect on controlling costs. James (1966) reported that mechanical handling and automation to replace scarce labor were a primary objective in industrial enterprises.

Electronic scales are available for most forage and feed wagons to permit the farmer to accurately weigh each ingredient added to the load for a balanced ration (Skromme, 1973). Automatic feed metering has been developed by the National Institute of Agricultural Engineering and Rationalization at Wageningen for pig feeding. The amount of feed can be adjusted depending on a reading obtained by scanning a graph. The metering device, an electromagnetic vibrating device, has been reported by Huizing (1973).

McGinty (1964) has reported the use of a loadcell with a weight controller to automate feed proportioning (Baldwin-Lima-Hamilton PTL load system). No problems were experienced with the control unit. The correct weight could be achieved by adjusting the set point to the desired amount of feed.

Hyer (1966) discussed the design criteria of a belt scale integrating system in which a multilever pivot type scale was designed under a belt conveyor. The electronic weighing system consisted of a DC tachometer, a generator and strain gages. The variation in output signal due to a temperature variation of 37.8°C was less than 0.1 percent. The significance of the moving conveyor related to the amount of material on the scale was also discussed.

Hyde et al. (1971) described an automatic system for proportioning concentrate into a variable flow of forage for feed preparation for dairy cattle. The forage weigher was a constant speed conveyor supported on a pivot at one end and on a variable differential transformer loadcell at the other end. The loadcell output was an amplitude modulated AC voltage proportional to the weight of the material flowing through the conveyor. The control system used the flow signal to control the speed of a DC motor driving an auger which delivered concentrate in proportion to its speed. Adjustment was required to compensate for temperature in the forage weigher loadcell and modulator components. The linearity and stability of the system were acceptable for the application of weighing forage and concentrate but the zero shift in the forage flow sensing stage was significant and had to be compensated for manually.

The use of automatic continuous weighing equipment has become widespread. The benefits of these systems are higher production rates, reduced plant costs per unit of production, lower operating cost and more uniform quality. The principle of continuous weighing is to measure and control the rate of flow of a bulk material. A gravimetric belt feeder is normally employed as the metering device to control the flow of the material. The system is designed to measure the weight of material per unit length of belt and also the speed of the feeder belt. These two measurements are processed to give kg/min. Many different proportioning systems for automatic continuous weighing equipment have been described (Merrick Scale Mfg. Co., ADS 104).

A continuous roller weigher as normally used in industry has a roller mounted independently from the main conveyor frame. The load on the roller is transmitted to an indicator system. In a cantilever weigher, suitable for weighing silage, a small chain and flight conveyor has one end mounted on bearings and the other end supported on an electronic loadcell. A continuous weigher with a platform mounted beneath a belt conveyor has been developed at the National Institute of Agricultural Engineering (Dawson et al., 1976). An electronic loadcell is mounted at one end of the platform and the signal is integrated to measure total weight. The signal can be used to control a concentrate auger to supply the concentrate at a preset ratio to the main constituent. It was suggested that if it was operated for a long time the circuit should be re-zeroed each hour for accurate measurement.

Broderick and Portens (1967) explained weighing feeders as installed in a cement plant. The feeders were used for weighing and integrating. The controls are fast acting solid state systems. The weight transducer can be hydraulic, pneumatic or electronic but is usually electronic.

Batch weighing systems for batch mixing are used for small to medium farm operations where overhead costs must be low and labor costs are not critical (Henderson and Perry, 1966). Reece (1974) reported a small push-button centrally controlled feed mill which was designed and built to provide small lots of experimental rations used in research. The mill operated on a batch weighing principle in which a small hopper was provided for weighing each ingredient. The cost of the system was $1400 in 1972 and all control functions for weighing, mixing and transferring materials were push button controlled from a central control panel.

Stationary mounted hopper mixers equipped with suspension scales have been used in weighing feed rations. The scale system can be a platform or an electronic indicator unit attached to the stationary mixer. Air cylinders operated discharge gates on the bin, mixer and hopper to provide for push button or automatic operation (Henke Machine Inc. Bulletin).

Fritche (1962) described a batch weighing system at the Miami Margarine Co.. The weigh tank was suspended from an electronic loadcell attached to the ceiling. The amount of milk and edible oils was controlled by punched card controls in the control console. The control of weight was better than 0.1 percent for a 1500 kg batch.

A practical application of the horizontal mixer is the mobile mixer feeder designed onto a truck body. This gives a self-propelled unit but could also be designed as a trailer. Truck-mounted or trailer-mounted mixers are available in six sizes from 680 kg to 3650 kg. Most of the units are designed for handling small grain, shelled corn or ground feed. Some units are designed with larger conveyors to handle silage (Agricultural Materials Handling Manual, Section 3.2).

A truck-mounted three screw horizontal mixer, mounted to a truck frame, has four load transducers electronically linked to a scale indicator in the truck cab. This permits the truck driver to stop the mixer truck at a feed receiving point where he assembles and weighs the main feed components (Turnbull et al., 1969). The mobile units are usually operated by one man.

Many small livestock feeders use portable grinder-mixers. These units are capable of grinding both baled hay and grains. Small farmers are able to use these units instead of building very expensive central mills and storage facilities. These units are used where fewer than 1000 head of livestock are fed. The central mill setup including complete mixing facilities is used for larger lots and trucks are used only to haul and feed (Skromme, 1973).

2.3 Weighing of agricultural products

In Canada and the U.S. portable truck and railroad scales are available at grain elevators. The scales have mechanical or electronic read outs from simple mechanical dial or beam indicators to digital instruments and solid state printers. Digital scale readout conversion kits are available to convert any beam or dial head scale to a remote digital display (Weigh System Inc.).

Grain received at country elevators has to be weighed. In general the farmer drives the truck onto the scales in the elevator. The grain and truck are weighed and then the truck is dumped and the empty truck is weighed to determine the weight of the grain. If the grain is to be cleaned, it must be weighed as delivered and again after cleaning. The farmer must have free access to the scales when his grain is being weighed for the purpose of verifying that he has obtained the correct weight of his grain (The Board of Grain Commission for Canada,1956).

The scales in every grain elevator must be inspected at least once a year by inspectors of Weights and Measures Standards Division, the Department of Trade and Commerce. If a dispute as to the weighing accuracy of the scales arises, it shall be incumbent upon the owner of the elevator to prove that the scales are weighing accurately.

A terminal elevator as defined by the Canada Grains

Act is an elevator, the principal purpose of which is to receive grain upon or after the official weighing of the grain, to clean and sort the grain before it is moved forward (Canada International Grains Institute, 1975). Grain is usually weighed in the workhouse. However, some terminal elevators use track or truck scales which weigh the rail car or truck before and after unloading to give the weight of the grain received. Other terminals use a receiving hopper supported on a loadcell.

In most terminals the scale is located at the top of the workhouse at a height of 46 to 67 meters. Hoppers located above the scale serve as surge capacity to allow continuous grain flow. When the weigh hopper is empty, grain is dropped from the surge hopper into the scale as grain continues to flow into the surge hopper. The cycle is then repeated throughout the weighing process. Many types of scales exist. Manually operated lever scales are still used today but they require that the weight be recorded by a punch (type registering boom) on a ticket. These scales are gradually being replaced by or modified to fully automated electronic equipment with capacities ranging from 100 to 150 tonnes. The weight of each weighing is automatically recorded on tape.

Johnson et al. (1974) designed and constructed a portable weighing system for field use. This system is currently being used to weigh large hay packages. It consisted of a portable strain indicator with a switching and a balancing unit and three load sensing units or loadcells. Full scale capacity is 5670 kg, linearity is 2.1 percent of full scale and the resolution is less than 0.21 kg.

Computer processing of data collected by a digital data acquisition system is usually done by batch processing where the data for several months or more are processed at one time. This technique can be applied as a control function such as in automatic weighing of feeders. Jordan et al. (1969) developed a method for expanding the capabilities of multichannel digital data acquisition systems. The control system was designed to allow the advancing and filling operation to be done automatically. The recording of the tare weight and the final weight of the hoppers was done automatically. A force transducer, a semiconductor loadcell, was used to weigh each hopper at the filling station. The mechanical limitations were more restrictive in the design than any limitation imposed by the electronic components. Daily calibration provided adequate accuracy for the problems of feed utilization in turkey disease experiments.

The study of evapotranspiration by plants using lysimeters requires a weighing system of high accuracy. Voisey and Holbs (1972) described a system for weighing groups of lysimeters. They utilized a strain gage loadcell and electronic readout equipment. The system was calibrated by dead weight methods to obtain a higher accuracy of measurement. The capacity of the scale was 454 kg and was used for measuring weight changes of $\pm$ 22.7 kg in lysimeters weighing 180 kg. The resolution was 0.045 kg and the accuracy was 0.090 kg.

Willits and Ross (1974) designed and developed an automatic weighing system for use in a drying study. The system was developed to record the weight of nine samples simultaneously. Each sample was suspended from the free end of a cantilever beam which had four strain gauges attached in a Wheatstone bridge circuit. The power was supplied by a DC regulated power supply and the output from the bridge circuit was connected to a recording potentiometer. The four arm bridge provided automatic temperature compensation and compensation for electrical drift and creep was provided by a cam which unloaded the beam periodically. The accuracy of the system was 1.0 percent of full scale for sample weights of 100 g.

To obtain more accurate estimates of the power requirements of farm implements in field conditions the draft and ground speed must be recorded simultaneously. Harrison and Reed (1961) designed and applied a draft transducer using strain gauges. Transducer configurations of U-shape and ring types were used. The ring type provided more mechanical protection for the gages and was satisfactory for field use.

CHAPTER III

THEORETICAL CONSIDERATIONS OF MASS (WEIGHT) MEASUREMENT

3.1 Standards

The weight of a body is defined as the force exerted on the body due to the acceleration of gravity. Force, according to Newton's second Law of Motion, is defined by the equation

$$F = ma$$

where F will be newtons (N) when the mass (m) is kg and the acceleration (a) is m/s^2.

The standard force depends on standards for the mass (m) and the acceleration (a). The standard mass is a cylinder of platinum iridium called the International kilogram. It is kept in a vault at Sevrès, France. Acceleration is not a fundamental quantity but can be determined experimentally. The gravitational acceleration, g, is a convenient standard which can be determined by measuring the period and effective length of a pendulum. The acceleration can also be determined by measuring the change of speed of a freely falling body. The standard value of g is quoted for sea level at 45° latitude and is 9.806650 m/s^2. The value at any latitude (ϕ degrees) can be computed from:

$$g(m/s^2) = 9.78049\ (1 + 0.0052884 \sin^2\phi - 0.0000059 \sin^2 2\phi)$$

A correction for altitude, h (metres), above sea level is

$$\text{Correction } (m/s^2) = 10^{-6}[-(3.08055 + 0.0022 \cos 2\phi)h + 0.72(h^2/1000)]$$

An unknown weight may be measured by any of the following methods of weight measurement (Doebelin, 1966):

1. Balancing against a known weight.

2. Measuring the acceleration of a body of known mass.

3. Balancing against a magnetic force created by the interaction of a current carrying coil and a magnet.

4. Transducing the force to a fluid pressure and measuring the pressure.

5. Applying the force to some elastic member and measuring the resulting deflection.

The method of using an elastic deflection transducer for force measurement is widely used for both static and dynamic loads. The displacement can be measured directly or a strain gage may sense force and displacement in terms of strain.

3.2 Principle of operation of strain gages

The principle of operation of strain gages is that the electrical resistance of a conductor changes when it is subjected to mechanical deformation (Holman, 1966). The strain-resistance change relationship was discovered in 1856 by Lord Kelvin during his investigation of the electrodynamic properties of metals (Perry and Lissner, 1955). The original strain gages built by Simmons and Ruge had been assembled in place by cementing the wire itself directly to the test material. These original strain gages became well known as SR-4 gages.

3.3 Transducers employing bonded strain gages

The bonded strain gage is commonly used and takes the form of a flat grid of very fine wires or foil which is bonded with some type of cement to the surface under consideration. Many different types of bonded gages are available with resistance values of 60 to 5000 ohms and effective gage lengths of 0.4 mm to 152.4 mm. Typical force transducers using strain gages for weight measurement are shown in Fig. 3.1.

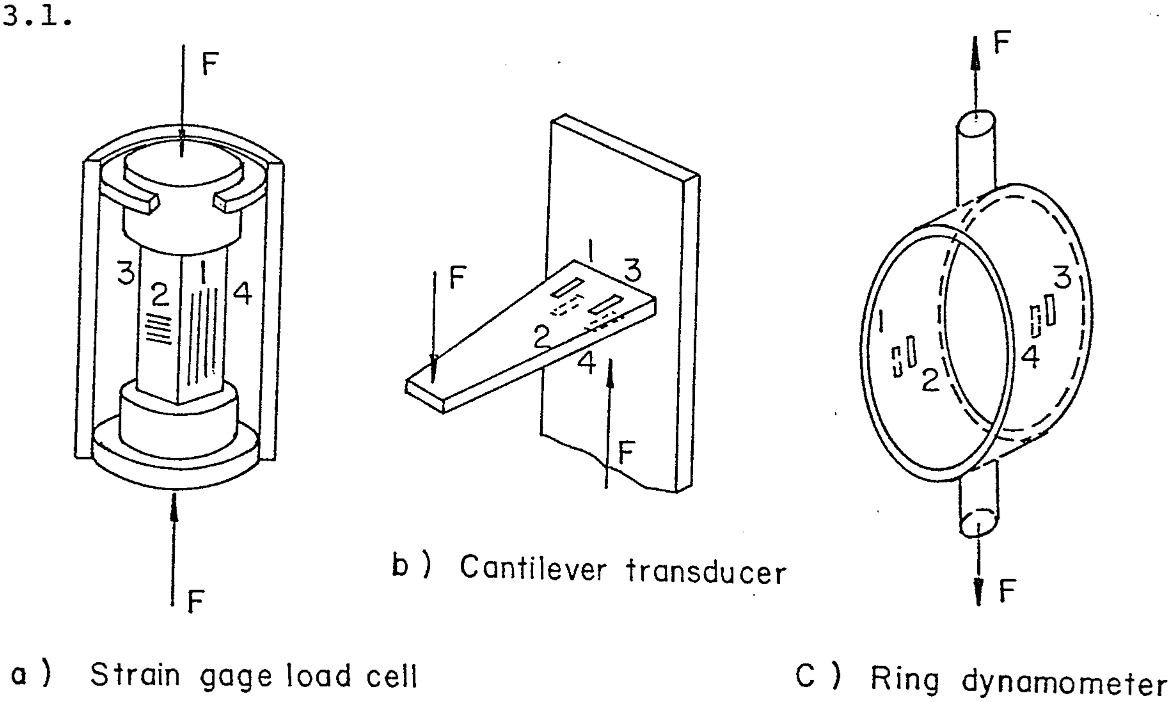

Figure 3.1 Typical application of strain gages for force measurement

In figure 3.1a a strain gage loadcell in which strain gages are bonded on all four sides is illustrated. Gages 1 and 3 sense the direct stress due to F and gages 2 and 4 are sensitive to the transverse stress due to Poisson's ratio. The maximum deflection under full load of such a loadcell is of the order of 0.025 to 0.381 mm (Considin, 1957).

The cantilever beam and proving ring (Figure 3.1b and Figure 3.1c) are used where adequate sensitivity cannot be achieved by the use of a direct tension or compression member. Four active strain gages provide four times the sensitivity of a single gage and temperature compensation is also provided. A ring dynamometer transducer under a tension load has gages 1 and 3 in compression and gages 2 and 4 in tension. With a bridge arrangement, these effects are all additive giving a larger output. The design and application of a ring transducer will be described later.

Any apparent instability in a static strain measurement could be caused by the strain gage itself or by the electrical measuring system. Instability is a shift in the null balance point. The factors affecting zero shift are (Perry and Lissner, 1955):

1. Incomplete temperature compensation of the active strain gage.

2. Instability of the Wheatstone bridge, power supply or amplifier.

3. Improper loading of strain gages.

4. Creep of one or more of the strain gages.
5. Insufficient protection from humidity.
6. Variations in the lead wires to individual gages.

The smallest detectable strain is limited by the thermal or Johnson noise voltage generated by the random motion of the electrons (Wilson, 1952).

In the application of strain gages for weight measurement the gage factor need not be accurately known since the overall system can be calibrated by applying known masses to the system and measuring the resulting bridge output voltage.

3.4 Ring dynamometer

Ring dynamometers have been used for draft or force measurements for years. Loewen et al.(1951) described a dynamometer utilizing electric strain gages in measuring force exerted on a metal cutting tool. Rings having relatively thin sections afford several advantages: (i) high ratio of sensitivity to stiffness, (ii) adequate stability against buckling, (iii) easily produced and simple gage bonding and (iv) heat flow in the opposite sides is relatively the same. Another advantage of the ring is that the strain produced on the surface can be estimated (Fig. 3.2a) by the following equations (Cook and Rabinowicz, 1963):

$$\varepsilon_{\theta=0} = 1.09\ FR/(Ebt^2) \quad \dots\dots\dots\dots\dots \quad (1)$$

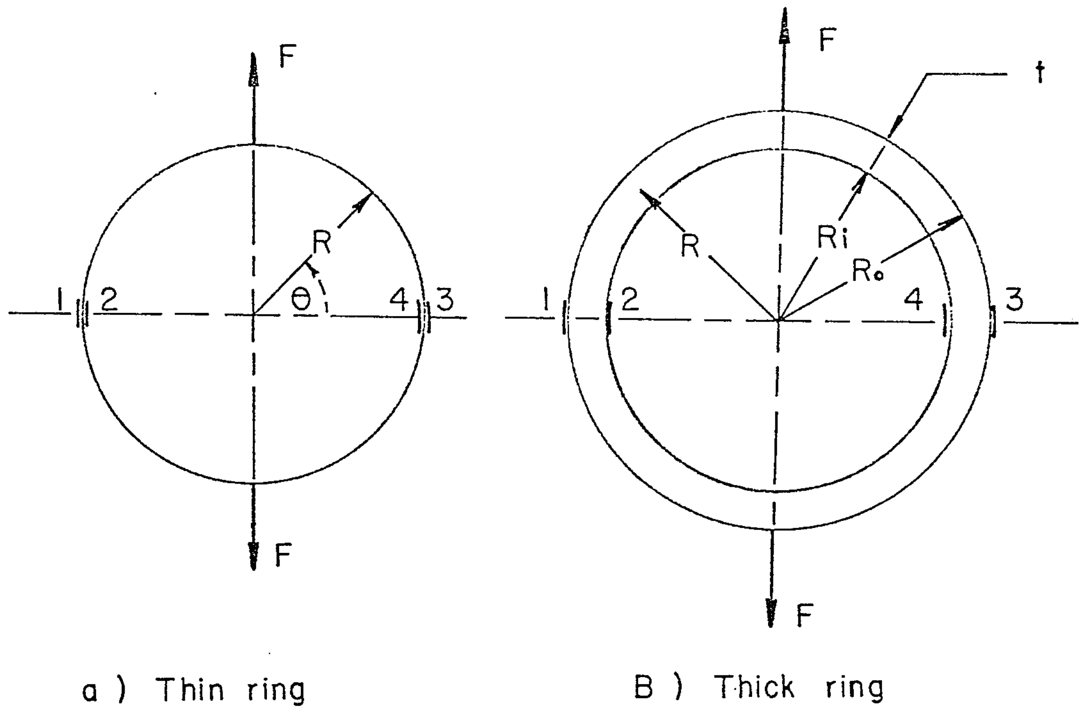

Figure 3.2 Circular ring dynamometer

$$M_{\theta=o} = 0.182FR \quad \text{. . . . .} \quad (2)$$

where

ε = elastic strain

F = load, N

R = radius of geometric axis of cross section, m

E = Young's modulus of material, N/m^2

b = width of ring, m

t = radial thickness of ring, m (t<<R)

M_θ = bending moment, N·m

Cook, Loewen and Shaw (1954) discussed dynamometer design and presented an example of a dynamometer that had proven satisfactory. In the thick ring the stress for both the inner surface and the outer surface can be calculated from the following equations (Scott and Droubi, 1970):

$$\sigma_i = -Mt(6R - t)/(6I(2R - t)) \quad . \quad . \quad . \quad (3)$$

$$\sigma_o = Mt(6R + t)/(6I(2R + t)) \quad . \quad . \quad . \quad (4)$$

where

σ_i = inner surface stress, N/m^2

σ_o = outer surface stress, N/m^2

I = section moment of inertia of the ring, m^4

From Hooke's Law $\sigma = E\varepsilon$ and $I = bt^3/12$

Thus the strains in a thick ring are:

$$\varepsilon_i(\theta = o) = 0.364\ FR(6R - t)/(Ebt^2(2R - t)) \quad . \quad . \quad . \quad (5)$$

$$\varepsilon_o(\phi = o) = 0.364\ FR(6R + t)/(Ebt^2(2R + t) \quad . \quad . \quad . \quad (6)$$

E = modulus of elasticity, N/m^2

The errors in the prediction of strain by the thin ring assumption over the thick ring assumption are:

$$\text{Error in } \varepsilon_i = 200/(6(R/t) - 1) \quad . \quad . \quad . \quad (7)$$

$$\text{Error in } \varepsilon_o = 200/(6(R/t) + 1) \quad . \quad . \quad . \quad (8)$$

Equations 7 and 8 show the percent error as a function of the ratio R/t. For large values of R/t the assumption of a linear stress distribution in the thin ring results in a satisfactory approximation.

3.5 Force control switches

The force control switches are built around a U-shaped deflection beam. A compressive load is applied to the upper half of this beam through a hardened ball and cup (Fig. 3.3a). Under the load the thin arm of the beam deflects inwardly. This deflection is utilized to operate the micro-switches. The control may use one or more of the four

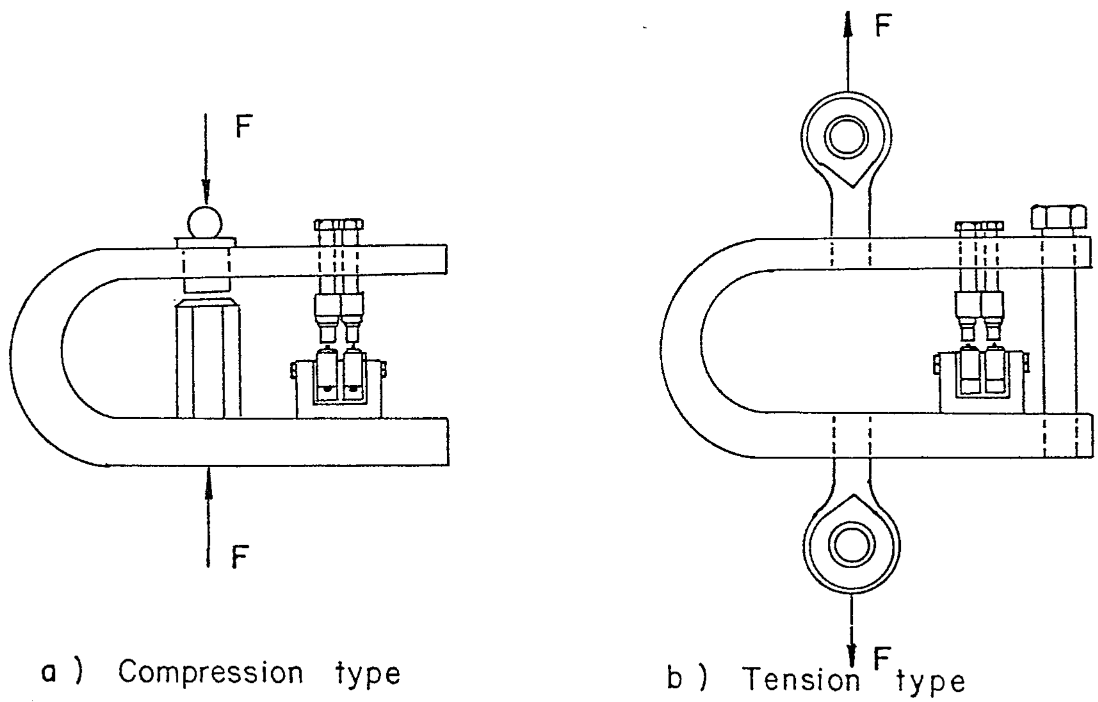

Figure 3.3 Force control switches

microswitches. The switches are all identical and are adjusted by turning finely threaded stainless steel screws. The screws are set so that for any desired loading the switches are activated, i.e. either opened or closed completing or interrupting an electrical circuit depending on the wiring configuration.

For tensile loads the force control switches are used the same as the compressive force control switches except that they are fitted with an overload safety bolt and are commonly supplied with a set of rod ends where the force is applied in a pulling manner (Fig. 3.3b). Figure 3.4 shows the typical commercial force control switches used in this project.

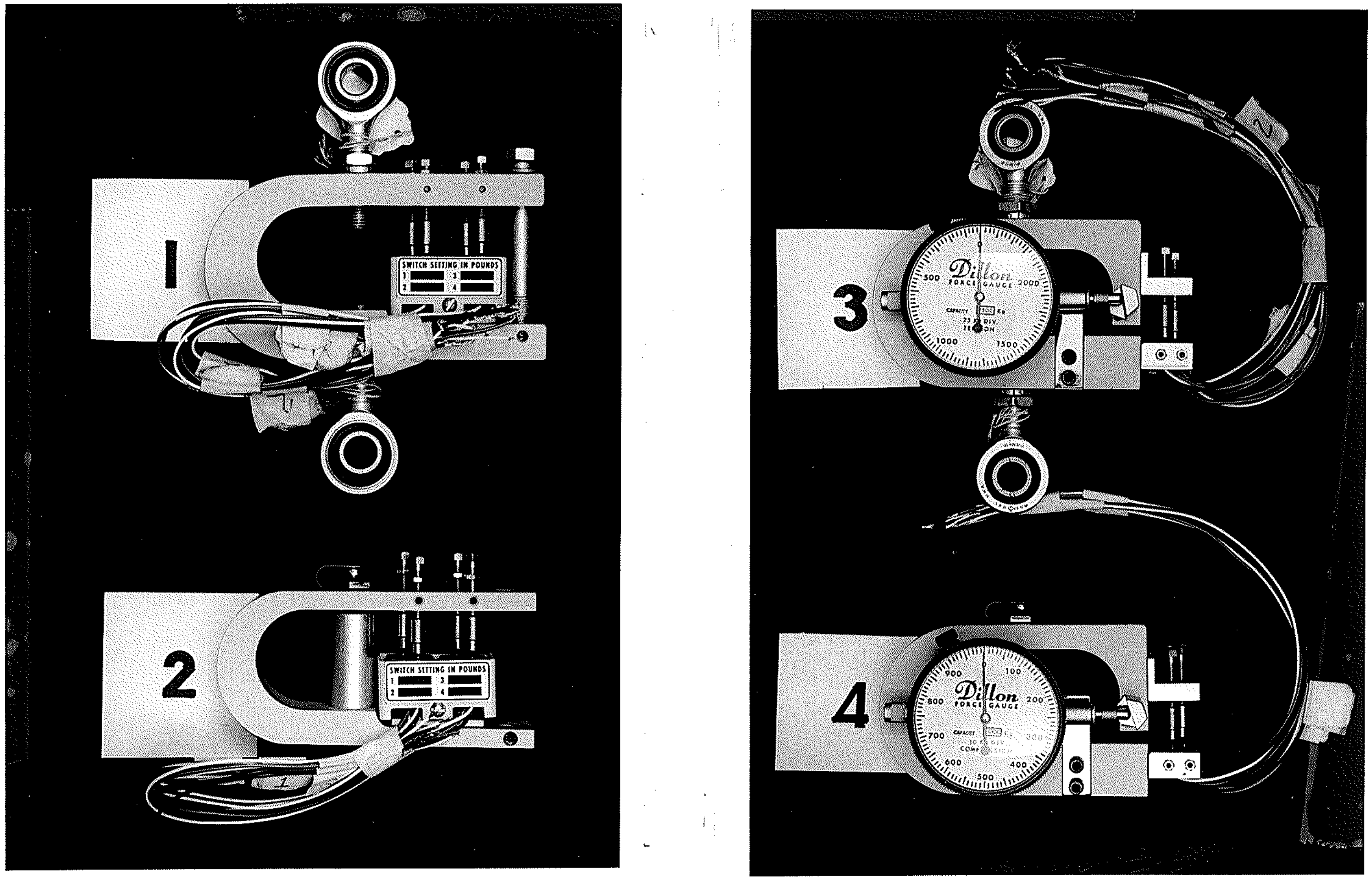

Figure 3.4 Typical commercial force control switch used in this experiment.
1. Model U force control switches, 2500 kg capacity
2. Model U force control switches, 1000 kg capacity
3. Model X force control switches, 2500 kg capacity
4. Model X force control switches, 1000 kg capacity

The deflection under the load or at the open end can be predicted by analytical methods. Laboratory testing as done in this project will give the most accurate results if the actual amount of deflection is required. In the testing described in this report the result of the deflection as indicated by the dial gauge reading or by the microswitch tripping was of major interest.

3.6 Electrical control circuits

Electrically powered farm equipment has been widely accepted for farm operations since control and operation is simplified. The basic functions of electrical control circuits can be:

1. to control (start and stop equipment)
2. for safety (low voltage control, fuses, circuit breakers)
3. for comfort (thermostats and humidistats)
4. to save labor and time (remote control of motors)
5. for automation (the operation of equipment without the need for human supervision).

Electrically automated control systems are becoming more important in farming operations. Various motor driven materials handling equipment such as augers, elevators, mixers, etc., play a large part in farm mechanization and proper controls ensure efficient operation. For small single phase motors, short circuit and overload protection for protecting the electric motor are provided. The contacts open whenever excessive current flows through the motor in an overload situation. Magnetic switches or motor controllers are used for many larger motors where a magnetic switch opens or closes the circuits to start or stop the motors. A small current through an electromagnet or coil is used to control movable contact points to control the circuit containing the main electrical supply to the motor.

Magnetic switches are used to control motors in the following situations (Shepardson, 1964):

1. When it is necessary to start and stop a motor by automatic devices such as thermostats or pressure switches. The thermostats or pressure switches cannot carry the full load current of the motor. In this case the automatic device controls the current to the magnetic coil.

2. Where the system must also be hand operated sometimes. In this case the magnetic switch is equipped with a selector for manual or automatic control.

3. Where it is necessary to prevent a motor from restarting after a power interruption. The magnetic switch is equipped with a start-stop push button control.

4. Where it is necessary to start and stop a motor from several locations. This requires the installation of a start-stop push button at each location.

The principle of automatic control can be divided into two types: (i) closed loop control and (ii) sequential control (Cox and Filby, 1972). In closed loop control the quantity to be controlled is measured by a suitable detector whose output is compared with a set value. The error or deviation between the measured and the set values is employed to operate a correcting unit which alters the measured quantity in a sense that tends to reduce the deviation. In sequential control the control action is such that one event is initiated by another or by a combination of other events. The events are registered by the opening or closing of switches and the control action is determined by the switching logic. An arrangement of switches responds to the signalling of events by the input sensors and the control of the operation is accomplished by the output actuator.

3.7 Determination of ingredient weights

Static calibration of the ring dynamometer determined the sensitivity of the weight transducer. Since the addition of the ingredients was sequentially controlled by the force control switches, the voltage output at each sequencing was proportional to the weight of the ingredient added. The amount of each ingredient was found by

$$Wt = (E_f - E_i)S \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

where

Wt = mass of ingredient, kg

E_f = voltmeter reading at the end of event, V

E_i = initial voltmeter reading, V

S = ring dynamometer sensitivity, kg/V

CHAPTER IV

EXPERIMENTAL EQUIPMENT

4.1 Introduction

Experiments were conducted to measure the amount of each ingredient conveyed into the hopper by the augers. The objectives of the experiments were to determine the accuracy and precision of the force control switches and the effect of temperature on the accuracy and precision. Static calibrations of the ring dynamometer were used throughout the period of the experiments. Figure 4.1 shows the static calibration of the ring dynamometer by using ten tractor weights. The mass of each tractor weight was measured to the nearest 0.1 kg on a platform scale. The signals from the ring dynamometer transducer were amplified and read out on a digital voltmeter.

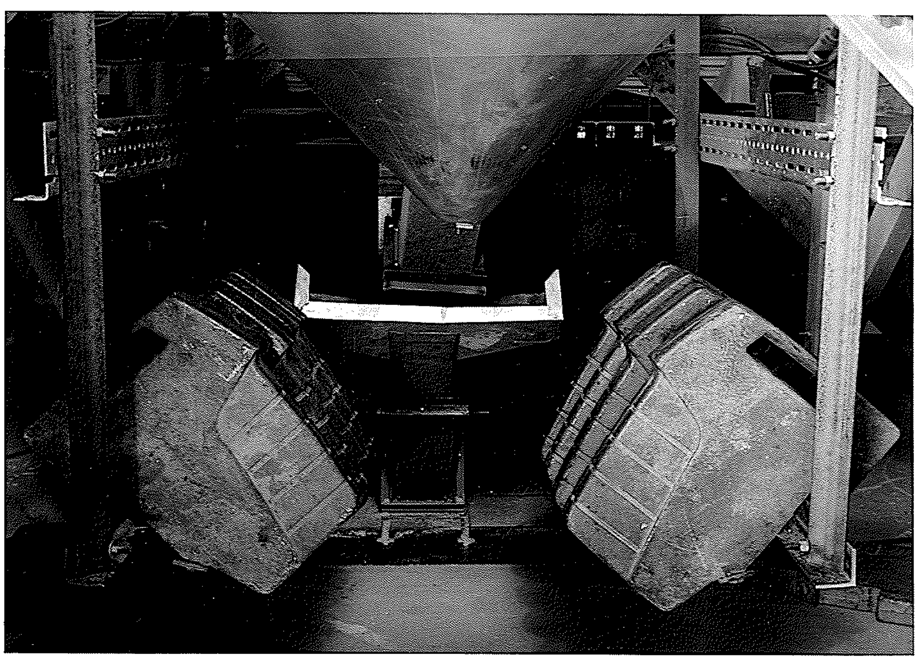

Figure 4.1 Static calibration of the ring dynamometer

The equipment was installed in the Agricultural Engineering Building at the University of Manitoba in the summer of 1976. Wheat was used to simulate the various ingredients that would be used in a real feed mixing situation. Figure 4.2 shows the handling equipment used in the simulated feed proportioning.

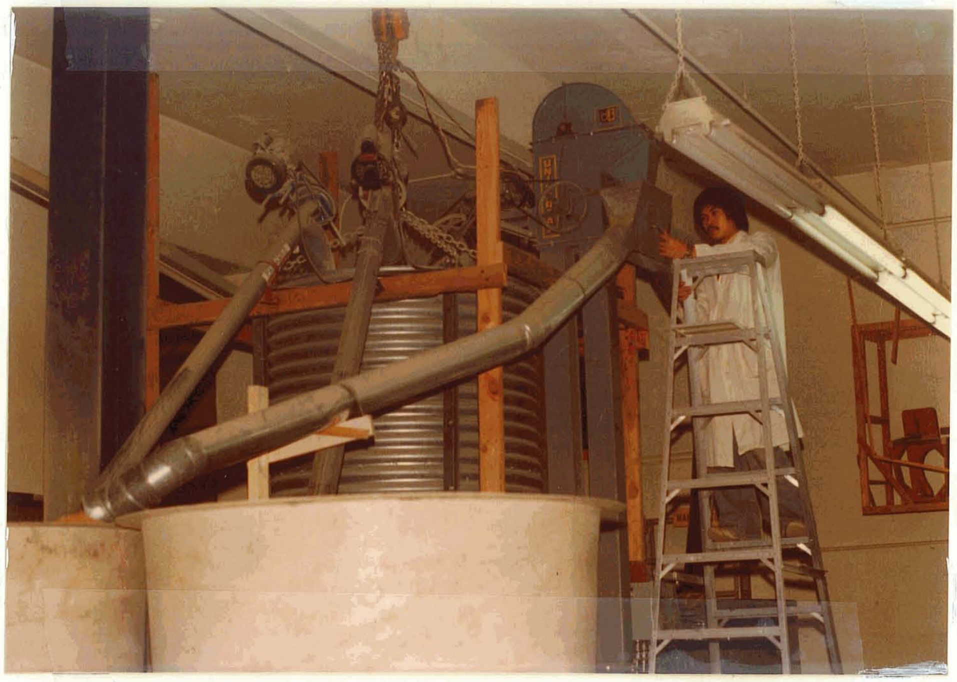

Figure 4.2 Handling equipment used in the experiment

4.2 Handling equipment

A galvanized steel bin, 1.22 m in diameter and 1.83 m high was used as a weighing hopper. It was suspended from the ceiling of the testing laboratory with the tension Model X force control unit and the ring dynamometer in series (see figure 4.3). A 45 degree conical bottom with a 10 cm by 10 cm discharge spout with a shutoff gate directed the grain to an elevator for recycling. Two 5.1 cm by 5.1 cm angle bars were provided on the hopper legs for static calibration purposes.

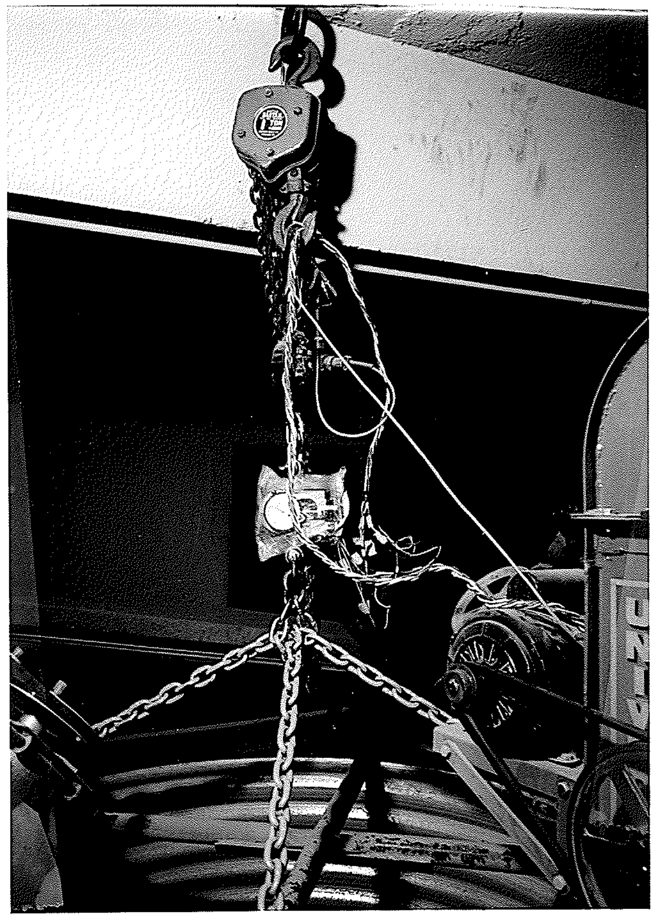

Figure 4.3 Installation for ring dynamometer, force control switch and weighing hopper

Three holding bins of 1.22 m diameter and 0.91 m depth were provided. One of the bins had an extension built on so that the capacity was increased to 1.96 m^3 (see figure 4.4). The large bin was placed at floor level while the two smaller bins, of 0.98 m^3 capacity each, were placed on stands

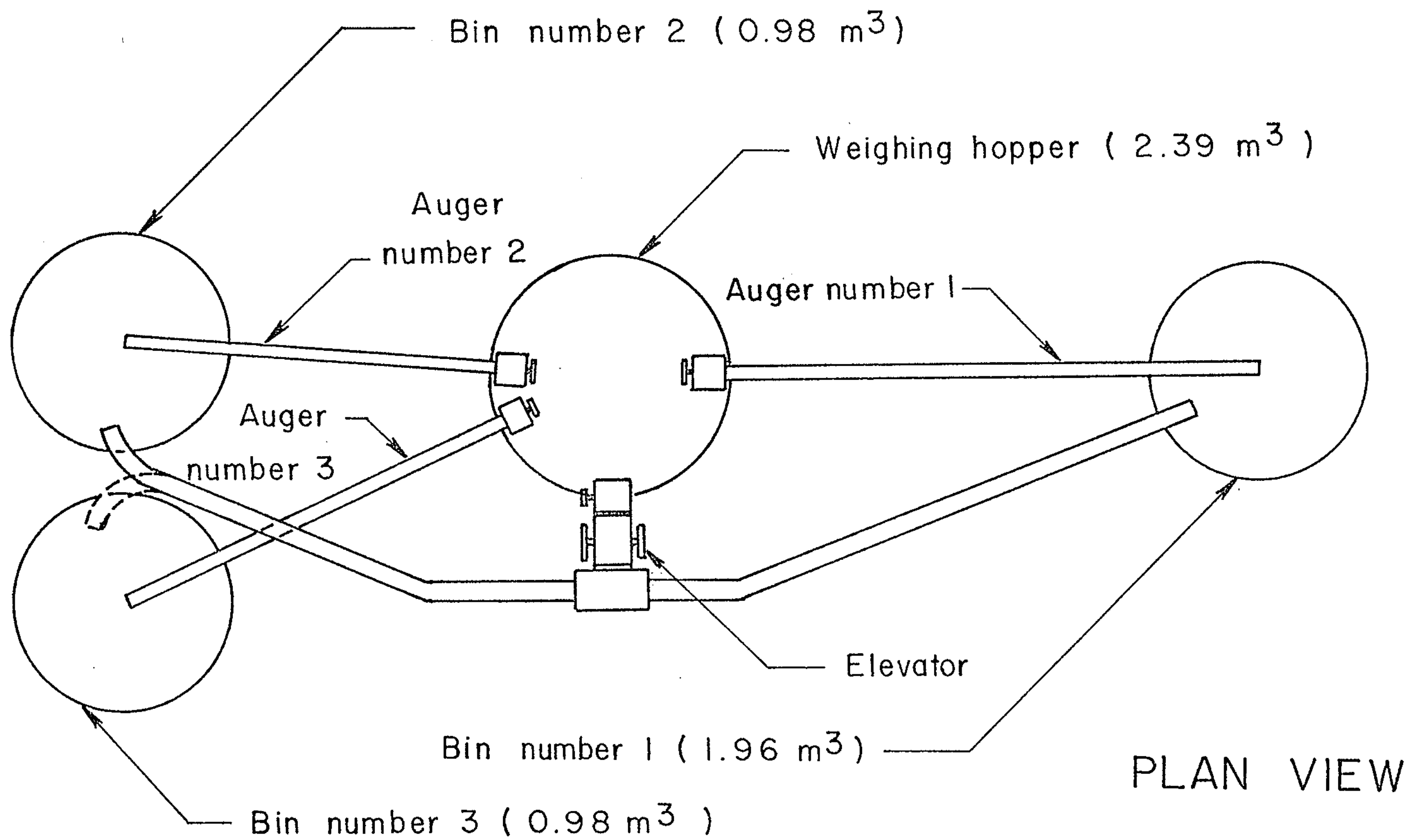

Figure 4.4 Schematic diagram of the testing apparatus.

1.22 m high. An auger (No. 1) 8.9 cm in diameter and 4.57 m long was used to convey wheat from the large bin to the weighing hopper. Two other augers (No. 2 and No. 3) 8.9 cm in diameter and 3.05 m long were used to transfer wheat from the bins to the hopper. Wheat was returned to the holding bins by a bucket elevator that was 3.05 m high. The wheat was directed to the elevator by the gate at the bottom of the weighing hopper. The elevator and augers were each powered by 373 W capacitor start electric motors.

CHAPTER V

EXPERIMENTAL PROCEDURE

5.1 Control circuit

Sequential control of the auger motors was essential to the operation of this weighing technique. Figure 5.1 shows the control panel for the electric motors. Figure 5.2 shows the control circuit wiring diagram of the control panel. The wiring diagram of the motor power circuit is shown in figure 5.3.

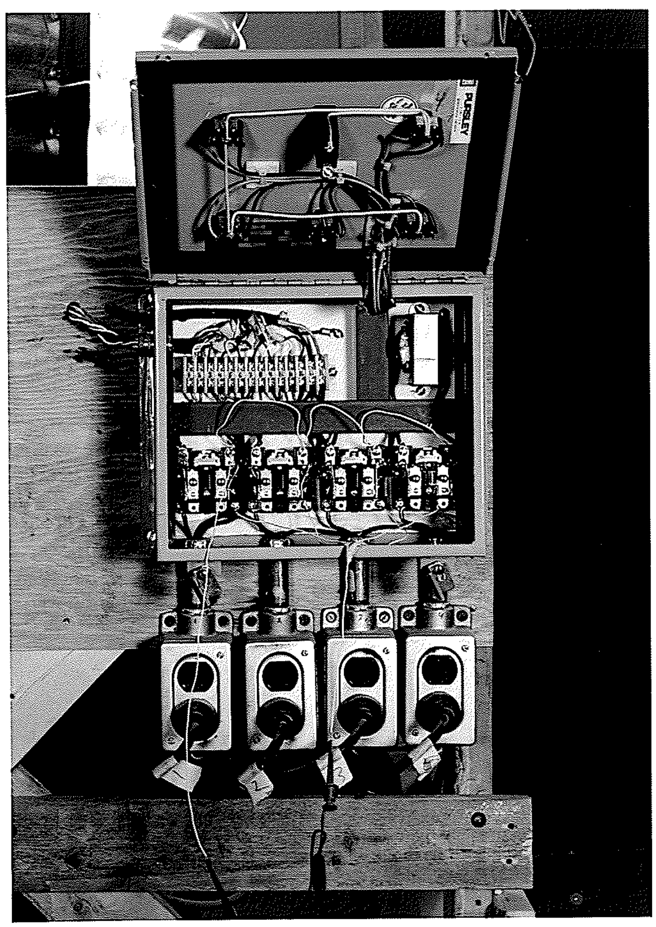

Figure 5.1 Control panel for electric motors

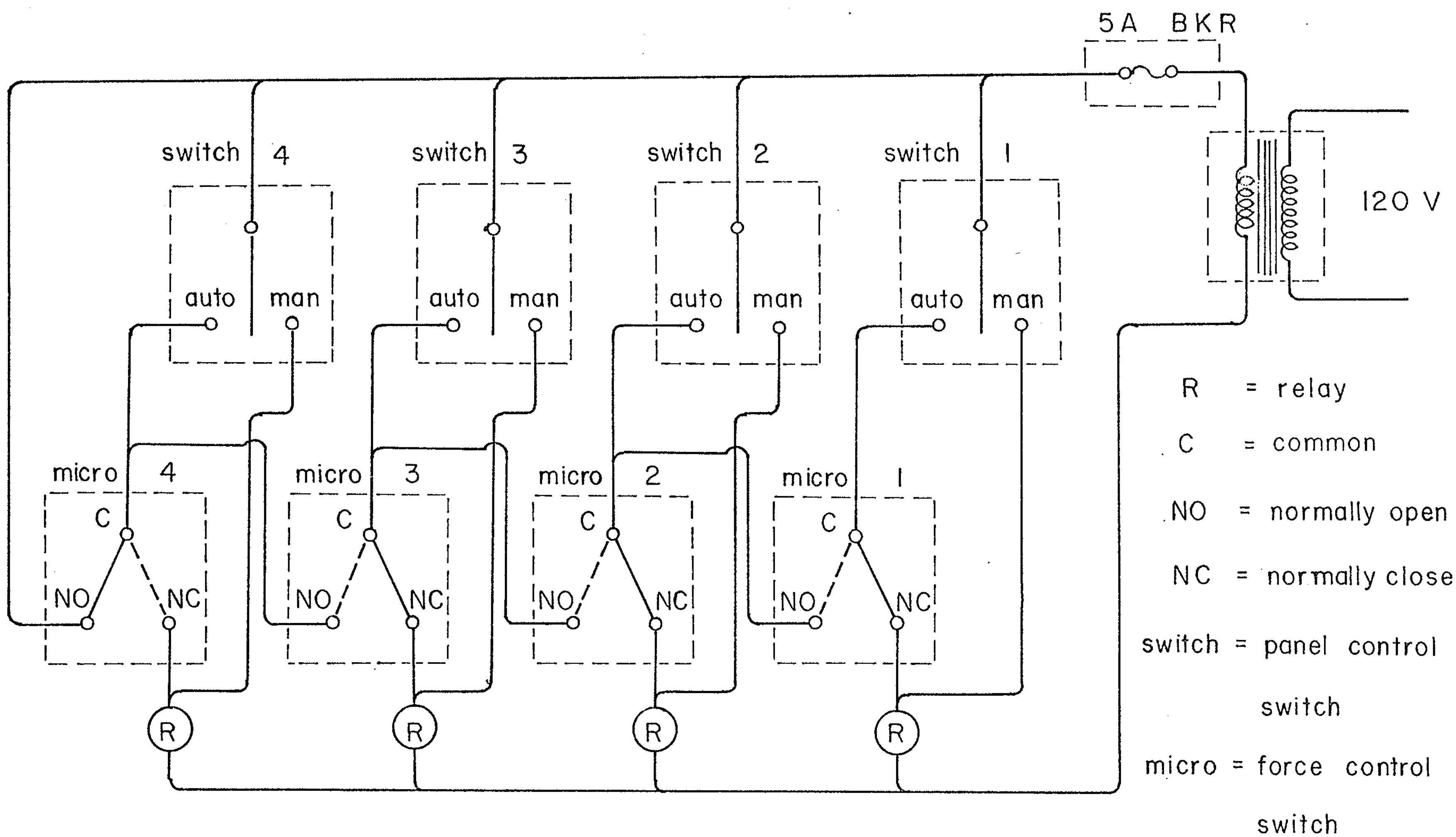

Figure 5.2 Wiring diagram for control circuit.

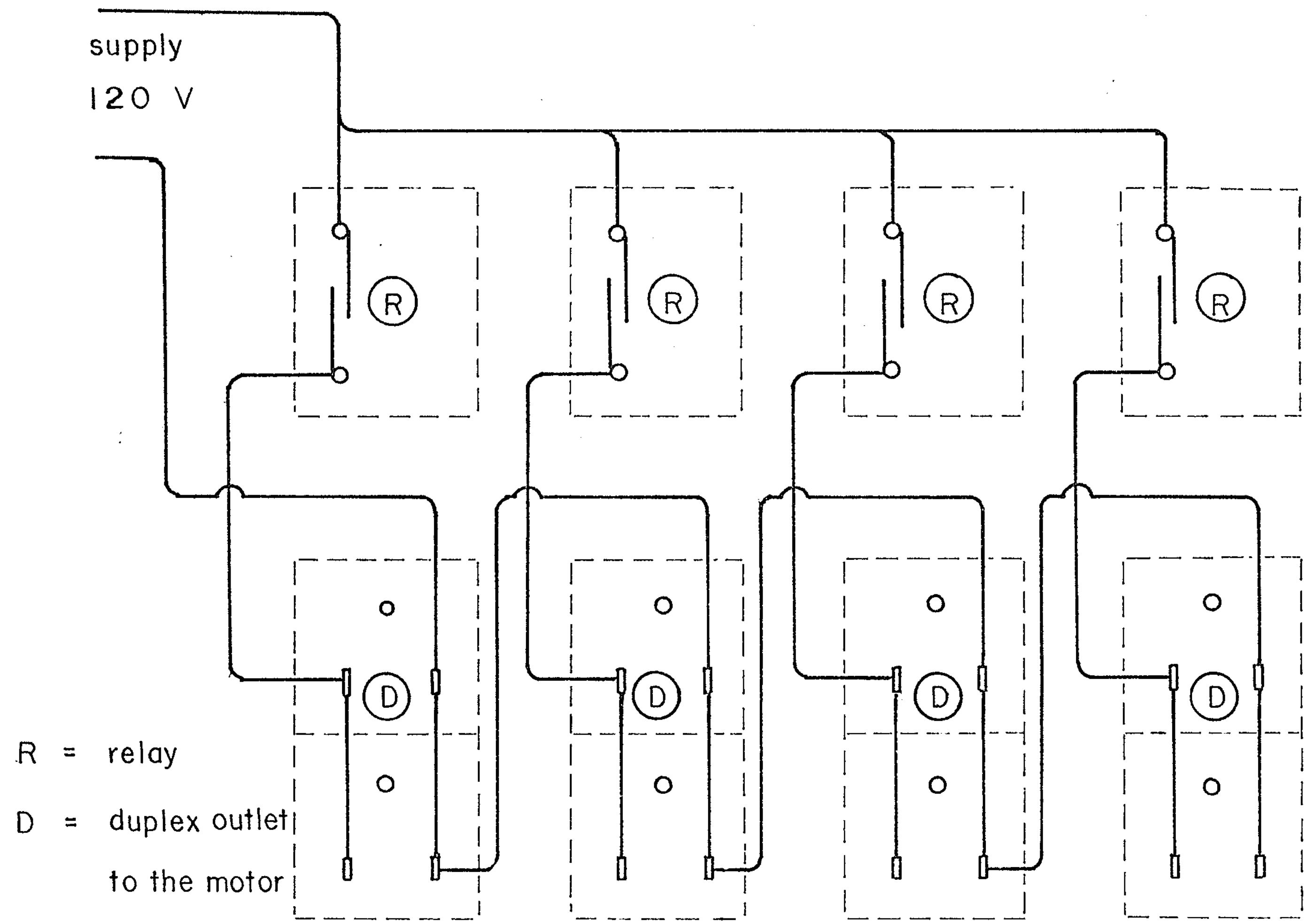

Figure 5.3 Wiring diagram for motor control circuit .

5.2 Setting the force control switches

The set points of the individual force control switches were selected depending on the amount of each ingredient desired in the simulated ration. The settings were accomplished as follows:

1. The dial gauge was zeroed for the tare weight of the weighing hopper (see figure 5.4).

2. Auger no. 1 was operated until the dial gauge indicated the desired amount of ingredient number 1. The microswitch controlling auger no. 1 was adjusted (see figure 5.5) so that auger no. 1 was turned off and the circuit to auger no. 2 was energized.

3. Auger no. 2 was operated until the dial gauge indicated that the desired amount of ingredient number 2 had been added. The microswitch controlling auger no. 2 was adjusted until auger no. 2 was switched off and the circuit to auger no. 3 was energized.

4. Auger no. 3 was operated until the dial gauge indicated that the desired amount of ingredient number 3 had been added. The microswitch no. 3 was then adjusted so that auger no. 3 was switched off.

It would have been possible to extend the system to a fourth ingredient. This was not done. Instead microswitch no. 4 was used to control the bucket elevator for emptying the weighing hopper and refilling the holding bins 1, 2 and 3. Microswitch no. 4 was set to shut off the bucket elevator

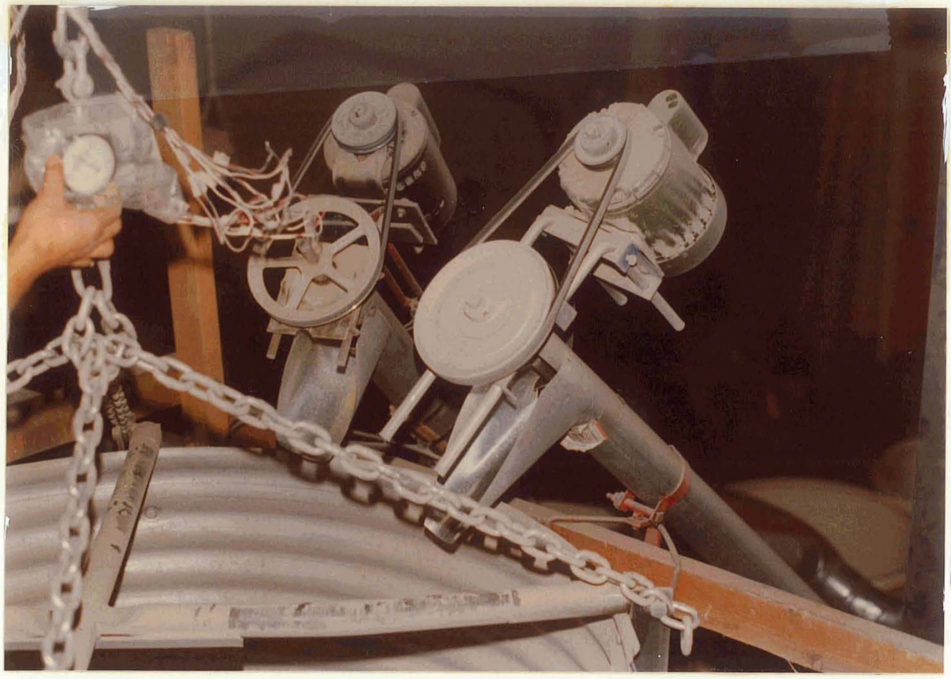

Figure 5.4 Zero reading on the dial gauge

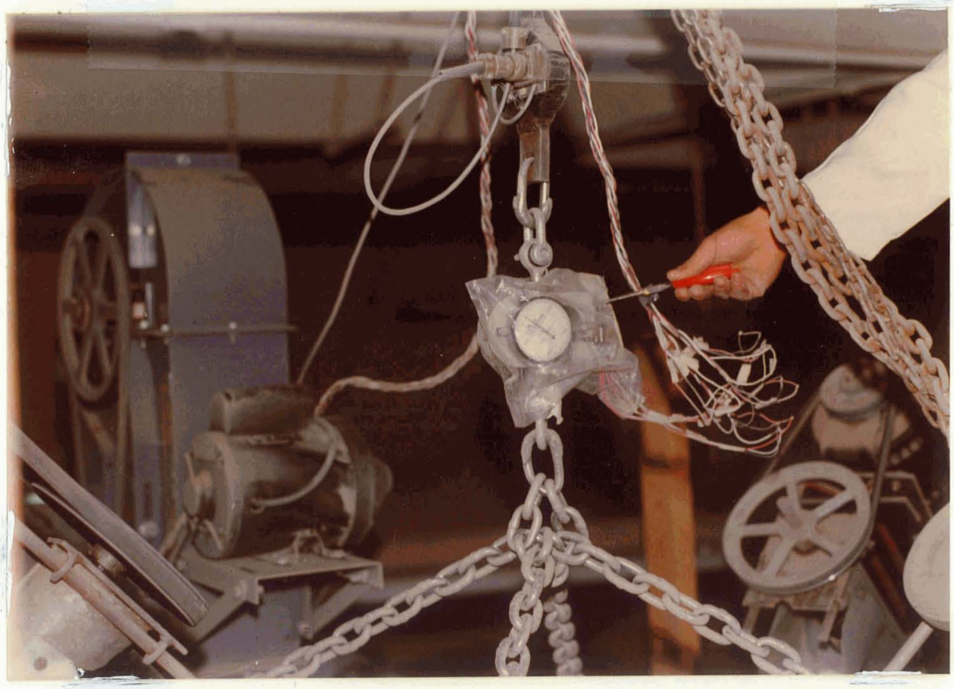

Figure 5.5 Adjusting microswitch for controlling motor

when the weighing hopper was empty.

By the above method the setting of the force control switches was accomplished and the control circuit in figure 5.2 was ready to operate the augers 1, 2 and 3 and the elevator in the proper sequence by using only switch no. 1 on the panel in the auto-position while the other switches were in the off-position. To unload the hopper, switch no. 4 on the panel was switched to the auto-position while switch no. 1 was in the off-position. The slide gate at the bottom of the hopper was opened and the grain flowed freely to the elevator leg and was elevated and returned through the down spouts to the bins. When the weighing hopper was empty, the elevator would stop automatically by operation of microswitch no. 4.

5.3 Procedure for testing accuracy of set-point adjustment

Three different feed ingredient ratios were simulated. The weight ratios (in kilograms) were 200:300:500, 500:300:200 and 700:200:100. The purpose of the tests was to determine the accuracy of the force control switch setting in proportioning the desired ratios. For each ratio, five settings of the force control switches were made to determine the precision and accuracy of the settings. One setting was selected for ten replication tests to investigate the precision of the control instrument.

5.4 Measurement of Temperature

The effects of temperature on the weighing device had to be determined since the average temperature in Winnipeg can vary from a low of approximately -20°C during January to a high of approximately 30°C during July (Environment Canada, 1975). For low temperature testing a centrifugal fan was used to blow cold outside air through a duct to impinge on the force control device. For high temperature testing a 600 W electric heater was placed in the fan duct and hot air was conveyed to the instrument. Both the low and the high temperature testing temperatures were controlled by adjusting the air flow of the fan. Thermocouples (copper - constantan) were provided to measure the temperature at the strain gage ring dynamometer and at the force control device.

5.5 Temperature effect test

The simulated feed ration with the ratio of 500:300:200 was used to test the effect of temperature on the force control switches. Cold outside air, air at room temperature and electrically heated air were combined as necessary to provide operating temperatures from -20°C to +40°C in 10°C increments. An air duct was used to bring the air to the force control switch locations. Five tests were run at each temperature.

CHAPTER VI

RESULTS AND DISCUSSION

6.1 General considerations of the force control instrument

The dial gauge on the force control instrument (Dillon and Company) used in this experiment read 2500 kg full scale, 25 kg per division. The least count of the dial gauge was therefore approximately 2.5 kg. The set points for the microswitches were determined from the dial gauge reading. The error due to setting the microswitches from the dial gauge was of the order of ± a least count, i.e. ± 2.5 kg. The error of when the microswitches were activated was of course a different matter to be discussed below.

Accuracy and precision were defined and calculated as follows for the purposes of this study (Bragg, 1974; Holman, 1971):

$$\text{Accuracy} = \text{maximum error}$$

$$\text{Accuracy (percent)} = 100(M_o - M_d)/M_d$$

where

M_o = Amount obtained, kg

M_d = Amount desired, kg

Sample calculation (data from Table 3) -

$$\text{Accuracy (percent)} = 100(197.8 - 200)/200$$
$$= -1.10 \text{ percent}$$

The negative sign indicates that the maximum error in the amount obtained was 1.10 percent low compared to the desired amount.

$$\text{Precision} = \text{maximum deviation from the mean}$$

$$\text{Precision (percent)} = 100(M_a - M_{mx})/M_a$$

where

M_a = Average amount obtained, kg

M_x = The amount obtained that had the greatest value of $M_a - M_{mx}$ kg

Sample calculation (data from Table 3) -

$$\text{Precision (percent)} = 100(199.5 - 197.8)/197.8$$

$$= 0.85 \text{ percent}$$

Precision can also be defined by use of the standard deviation. For normally distributed data the following distribution would be expected (Bragg, 1974):

(i) Mean ± 1S would include 68.3 percent of the observations,

(ii) Mean ± 2S would include 95.5 percent of the observations, and

(iii) Mean ± 3S would include 99.7 percent of the observations.

6.2 Temperature control

Room temperature was controlled during the period of test. The temperature of 20 ± 1°C was determined by the room thermostat and was read on a thermometer during the testing of the force control switches for accuracy and precision. For the effect of temperature changes from room temperature, the temperature of air flowing over the force control switches was controlled as described in section 5.5. The temperature varied from the desired temperature by approximately ±1°C (see Table 10).

6.3 The effect of zero shift in the strain gage ring dynamometer

Zero shift in the ring dynamometer used as a secondary standard in this experiment was not a serious problem. The time required for conveying each ingredient to the weighing hopper was from 1 to 6 minutes. The difference between the initial voltmeter reading and the final voltmeter reading was proportional to the amount of each ingredient added. This technique of measurement minimizes the effect of zero shift (Perry and Lissner, 1955).

6.4 Calibration of the dial gauge and ring dynamometer

The dial gauge on the tension force control device was calibrated in the testing machine. Figure 6.1 shows the calibration curve. The relation shows that the dial gauge was in good agreement with the testing machine as the slope of the line was nearly one. The accuracy of the testing machine was 0.2 percent of reading.

A typical calibration of the ring dynamometer for the period of testing is shown in Figure 6.2. Other calibrations are shown in Appendix 1. Three static calibrations were performed for each test of setting the force control switches for different ingredient proportions in the tests of accuracy and precision (before the tests, midway in the period of the tests and after the tests). The calibration masses versus the voltage output produced a linear relationship. The average slope of the three calibration curves was used to represent the static sensitivity of the ring dynamometer and was used in the calculation of the amount of each

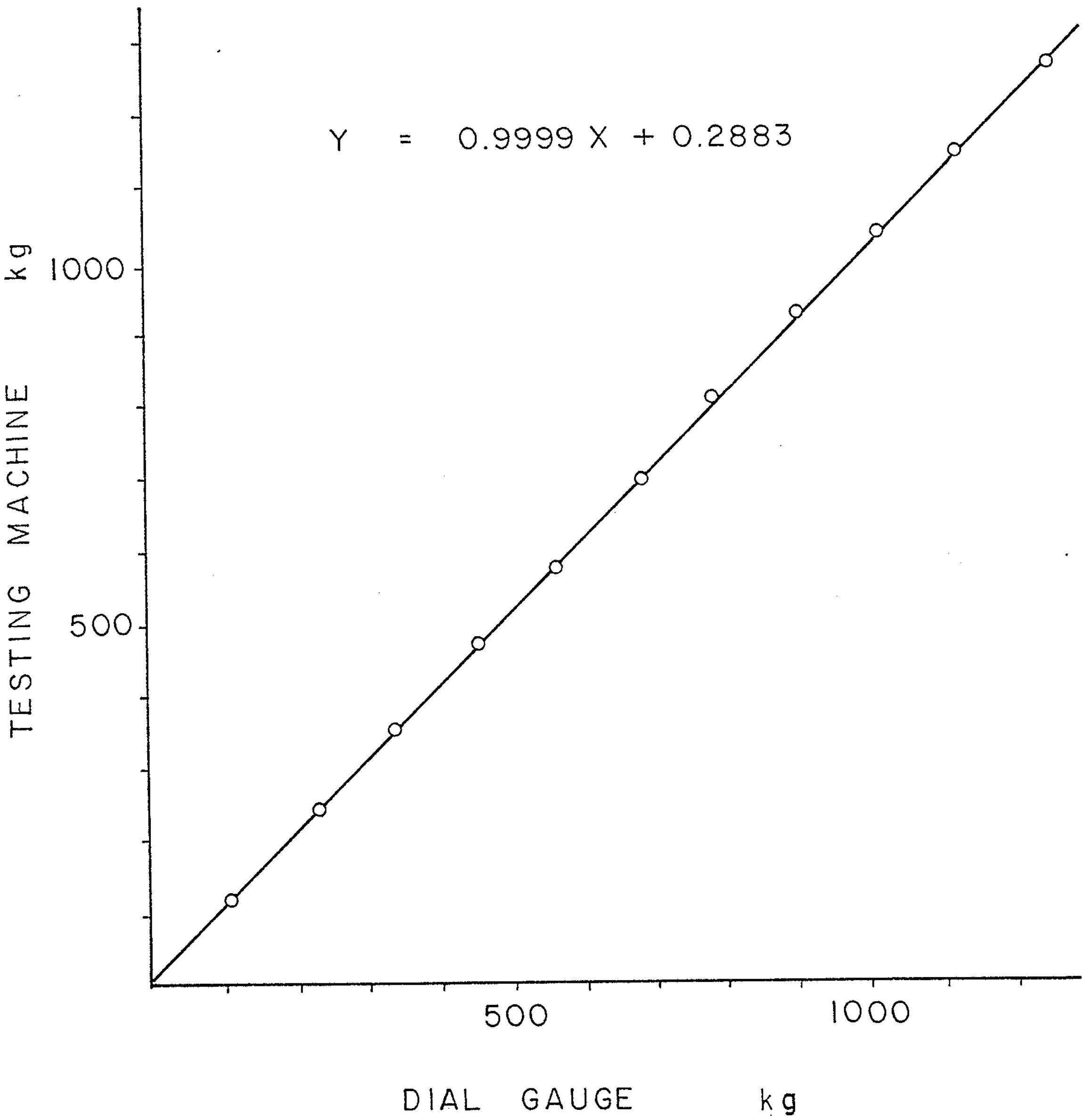

Figure 6.1 Calibration of the dial gauge tension force control device

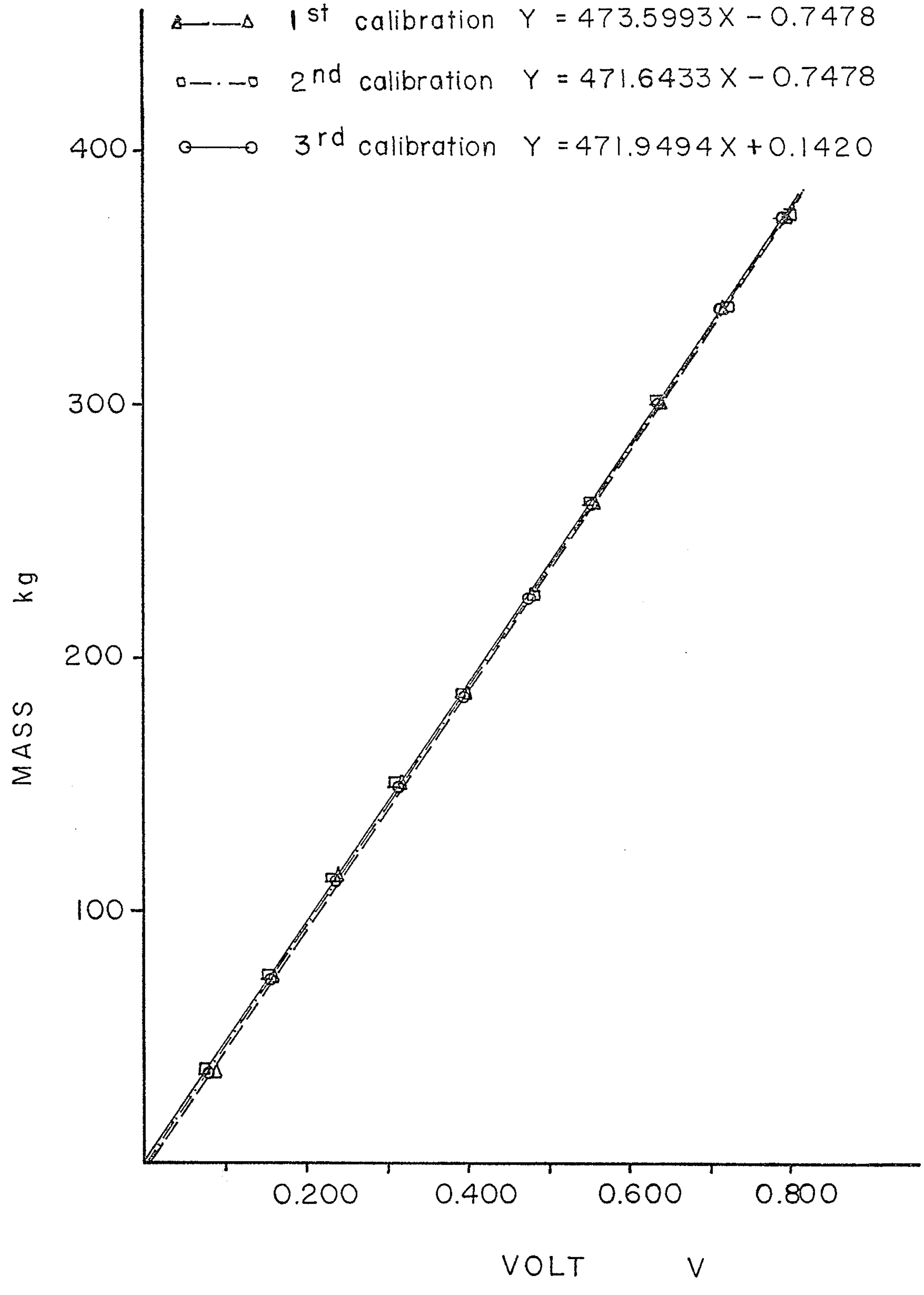

Figure 6.2 Typical ring dynamometer calibration curve. Ingredient ratio 200:300:500

ingredient.

The calibrations of the ring dynamometer used in the test of temperature variations are shown in Appendix 2. Two static calibrations were performed for each temperature variation test. The average slope of the calibration curves was used in the calculation of the amount of each ingredient.

6.5 The effect of electrical noise in the ring dynamometer circuit

Noise present in the voltmeter reading was probably the effect of vibration in the ring dynamometer due to temperature gradients and structural vibrations as well as instabilities in the amplifier and voltmeter. It was observed that the signal varied by ± 0.002 volts from the mean reading at constant load. This error in the calculation of the amount of the ingredient would be

error = ± 0.002 (sensitivity) kg

The error would be 0.9 kg when the sensitivity used in the calculation was 473.13 kg/V.

6.6 Testing for ingredient ratio of 200:300:500 (kg)

6.6.1 Results of setting the ingredient ratio of 200, 300 and 500 kg

Five trial settings of the microswitches to activate at 200, 500 and 1000 kg were done to obtain the ingredient ratios of 200, 300 and 500 kg, respectively. Table 1 shows the results of the settings at 200, 500 and 1000 kg. The

Table 1 Results of microswitch settings for desired cumulative ingredient amounts of 200, 500 and 1000 kg. (temperature 20°C)

run	Desired amount 200 kg		Desired amount 500 kg		Desired amount 1000 kg	
	Amount obtained kg	% difference	Amount obtained kg	% difference	Amount obtained kg	% difference
1	196.3	1.85	508.6	1.72	1011.5	1.15
2	200.1	0.05	508.0	1.60	999.5	0.05
3*	197.8	1.10	503.7	0.74	1010.1	1.01
4	201.5	0.75	509.4	1.88	1010.0	1.00
5	199.6	0.20	503.4	0.68	1010.8	1.08
Average	199.1	0.45	506.6	1.32	1008.4	0.84

*Run number 3 was repeated 10 times to determine precision (see Table 3).

amounts obtained for the different runs with repeated settings were compared to see how close the amounts agreed. The operation of the microswitches depended on the deflection of the beam of the force control device. The deflection may have been uniform for the runs but the accuracy of setting the microswitches could vary. The most accurate settings of the five trials was run number 2 with 200.1, 508.0 and 999.5 kg for 0.05, 1.6 and 0.05 percent variation from the desired amounts of 200, 500 and 1000 kg respectively. The maximum differences were less than 2 percent for all tests. These percentage differences define the accuracy of the proportioning of the ingredient ratios desired.

The individual ingredient amounts and the variation from the desired amounts as set by the microswitches are shown in Table 2. The amount of each ingredient depended on the accuracy of the microswitch setting as well as the actual accuracy of the switch tripping. Amounts different from the desired amounts of an ingredient could result from an incorrect setting or a faulty trip of the microswitch. Any one ingredient amount depends on the settings of two different microswitches. In this experiment the tripping of one microswitch actually affected two ingredients (except for microswitch number three which tripped at the end of each test). The maximum errors in each ingredient were 1.85, 4.10 and 1.68 percent deviation from the desired amount of each ingredient for the ingredient ratio 200:300:500 kg respectively. The minimum errors were 0.05, 1.27 and 0.10 percent respectively.

Table 2 Results of microswitch settings for the ingredient ratio of 200, 300 and 500 kg. (temperature 20°C)

run	Desired amount 200 kg		Desired amount 300 kg		Desired amount 500 kg	
	Amount obtained kg	% difference	Amount obtained kg	% difference	Amount obtained kg	% difference
1	196.3	1.85	312.3	4.10	502.9	0.58
2	200.1	0.05	307.8	2.60	491.6	1.68
3*	197.8	1.10	305.9	1.97	506.4	1.28
4	201.5	0.75	307.9	2.63	500.5	0.10
5	199.6	0.20	303.8	1.27	507.5	1.50
Average	199.1	0.45	307.5	2.5	501.8	0.36

*Run number 3 was repeated 10 times to determine precision (see Table 3).

It was difficult to obtain the amounts of each ingredient exactly as desired because the amount of each ingredient was affected by the ingredient preceding or following.

6.6.2 Precision test for desired ingredient ratio of 200: 300:500 (kg)

Run number 3 of the microswitch setting tests for an ingredient ratio of 200:300:500 (kg)(Section 6.6.1) was extended to ten repetitions to see how much the amounts deviated from the desired amount for the same microswitch settings. The repeatability or the precision of the microswitch setting was determined by this test. The results are shown in Table 3. The precision for the ingredient ratios were 0.84, 0.49 and 1.19 percent of the mean amounts obtained for each ingredient for the desired ratio 200, 300 and 500 kg, respectively. Table 3 also gives the 95 percent confidence interval for the mean (Bragg, 1974). The high degree of precision obtained, coupled with lower accuracy, would indicate that if the microswitches had been set more accurately to the desired amounts then both precision and accuracy would be acceptable.

6.7 Testing for ingredient ratio of 500:300:200 (kg)

6.7.1 Results of setting the ingredient ratio of 500, 300 and 200 kg

Five trials of setting the microswitches for the cumulative ingredient amounts of 500, 800 and 1000 kg were performed to obtain the ingredient ratios of 500, 300 and

Table 3 Precision test for the microswitch setting for the ingredient amounts of 200, 300 and 500 kg.

run	Desired amount 200 kg	Desired amount 300 kg	Desired amount 500 kg
	Amount obtained, kg	Amount obtained, kg	Amount obtained, kg
1	197.8	305.9	506.4
2	200.4	305.9	504.5
3	200.9	307.0	501.5
4	200.6	307.2	498.8
5	199.9	307.6	497.1
6	198.3	307.5	505.9
7	199.7	308.7	504.1
8	197.9	309.9	500.7
9	200.1	307.7	503.8
10	199.3	306.2	506.1
Mean	199.5	307.4	502.9
Standard Deviation	1.13	1.26	3.22
Accuracy (%)	1.10	3.30	1.28
Precision (%)	0.84	0.49	1.15
95% Confidence interval for mean (kg)	199.5 ± 0.8	307.4 ± 0.9	502.9 ± 2.3

Table 4 Results of microswitch settings for desired cumulative ingredient amounts of 500, 800 and 1000 kg. (temperature 20°C)

run	Desired amount 500 kg		Desired amount 800 kg		Desired amount 1000 kg	
	Obtained amount kg	% difference	Obtained amount kg	% difference	Obtained amount kg	% difference
1	505.4	1.08	799.3	0.09	1008.5	0.85
2*	510.4	2.08	805.7	0.71	1014.9	1.49
3	507.9	1.98	801.0	0.12	1016.3	1.63
4	513.3	2.66	813.6	1.70	1020.3	2.03
5	508.0	1.60	810.4	1.30	1012.4	1.24
Average	509.0	1.80	806.0	0.75	1014.5	1.45

*Run number 2 was repeated 10 times to determine precision (see Table 6).

200 kg respectively. Table 4 lists the results for the desired cumulative ingredient amounts of 500, 800 and 1000 kg. The maximum variations of the obtained amounts were 2.66, 1.70 and 2.03 percent from the desired amounts of 500, 800 and 1000 kg respectively. These maximum variations all occurred for the same run (i.e. No. 4) and seem to indicate that there was an error in the setting of the microswitches from the dial gauge on the force control device. Table 5 lists the obtained ratios compared to the desired ratio of 500, 300 and 200 kg. Run number four, when reduced to the ratios, does not appear to be in error excessively when compared to the other runs. This could indicate an error of the zero setting of the dial gauge thus significantly effecting only the first ingredient. The effect of errors in the settings of microswitches 1 and 2 could have produced an error in subsequent ingredient amounts. For example in run number 3 the second ingredient amount was 6.9 kg less than the desired amount while the third ingredient amount was 15.3 kg greater than the desired amount. This seems to indicate that microswitch number 2 was set lower than the desired amount resulting in a greater amount for the third ingredient since the setting of the microswitches was based on the dial gauge readings.

6.7.2 Precision test for desired ingredient ratio of 500, 300 and 200 kg

Run number 2 of the tests of setting the microswitches

Table 5 Results of microswitch settings for the ingredient ratio of 500, 300 and 200 kg.

run	Desired amount 500 kg		Desired amount 300 kg		Desired amount 200 kg	
	Obtained amount kg	% difference	Obtained amount kg	% difference	Obtained amount kg	% difference
1	505.4	1.08	293.9	2.03	209.1	4.95
2*	510.4	2.08	295.4	1.53	209.1	4.95
3	507.9	1.58	293.1	2.30	215.3	7.65
4	513.3	2.66	300.3	0.10	206.8	3.40
5	508.0	1.60	302.4	0.80	202.0	1.00
Average	509.0	1.80	297.0	1.00	208.5	4.25

*Run number 2 was repeated 10 times to determine precision (see Table 6).

for the ingredient ratios of 500, 300 and 200 kg was selected for 10 replications in order to test the precision of the microswitch settings. The results are shown in Table 6. The results indicate precisions of 0.22, 0.63 and 1.66 percent for the obtained ratios. The precision obtained for the ingredients was better than the accuracy for the ingredients. This indicates that once the microswitches are set, repeated use of the resulting ratio could be both accurate and precise.

6.8 Testing for ingredient ratio of 700:200:100 (kg)

6.8.1 Results of setting the ingredient ratio of 700, 200 and 100 kg

Five trials of setting the microswitches for the cumulative ingredient amounts of 700, 900 and 1000 kg were performed to obtain the ingredient ratio of 700, 200 and 100 kg, respectively. Table 7 lists the obtained amounts when the desired amounts were 700, 900 and 1000 kg. The maximum differences between the desired amount and the obtained amounts were 1.97, 1.40 and 0.72 percent variation from the desired amounts of 700, 900 and 1000 kg respectively. Minimum differences were 0.90, 0.12 and 0.32 percent for the desired amounts of 700, 900 and 1000 kg, respectively.

Table 8 lists the results in terms of the desired ratios of 700, 200 and 100 kg obtained from microswitch settings of 700, 900 and 1000 kg. The amount of the second ingredient was always less than the desired amount of 200 kg while the amounts of the first ingredient and the third in-

Table 6 Precision test for the microswitch setting for the ingredient amounts of 500, 300 and 200 kg.

run	Desired amount 500 kg	Desired amount 300 kg	Desired amount 200 kg
	Obtained amount, kg	Obtained amount, kg	Obtained amount, kg
1	510.4	295.4	209.1
2	510.1	296.0	206.8
3	510.7	298.3	206.3
4	510.8	296.9	207.2
5	511.0	298.6	205.8
6	509.8	296.3	204.9
7	509.3	296.6	211.0
8	510.2	299.1	207.7
9	510.7	295.1	208.2
10	510.7	295.7	208.7
Mean	510.4	296.8	207.6
Standard Deviation	1.66	1.40	1.78
Accuracy (%)	2.20	1.63	5.50
Precision (%)	0.22	0.63	1.66
95% confidence interval for mean (kg)	510.4 ± 1.7	296.8 ± 1.0	207.6 ± 1.3

Table 7 Results of microswitch settings for desired cumulative ingredient amounts of 700, 900 and 1000 kg.

run	Desired amount 700 kg		Desired amount 900 kg		Desired amount 1000 kg	
	Obtained amount kg	% difference	Obtained amount kg	% difference	Obtained amount kg	% difference
1	708.7	1.24	897.9	0.12	1006.3	0.63
2	706.3	0.90	892.7	0.81	1007.2	0.72
3	713.8	1.97	887.4	1.40	1005.7	0.57
4*	710.9	1.55	896.4	0.40	1003.4	0.34
5	708.5	1.21	896.8	0.36	1003.2	0.32
Average	709.6	1.37	894.2	0.64	1005.2	0.52

*Run number 4 was repeated 10 times to determine precision (see Table 9).

Table 8 Results of microswitch settings for the ingredient ratio of 700, 200 and 100 kg.

run	Desired amount 700 kg		Desired amount 200 kg		Desired amount 100 kg	
	Obtained amount kg	% difference	Obtained amount kg	% difference	Obtained amount kg	% difference
1	708.7	1.24	190.2	4.90	107.4	7.40
2	706.3	0.90	186.4	6.80	114.5	14.50
3	713.8	1.97	173.6	13.20	118.3	18.30
4*	710.9	1.55	185.4	7.30	106.9	6.90
5	708.5	1.21	188.3	5.85	106.4	6.40
Average	709.6	1.37	184.8	7.61	110.7	10.7

*Run number 4 was repeated 10 times to determine precision (see Table 9).

Table 9 Precision test for the microswitch setting for the ingredient amounts of 700, 200 and 100 kg.

run	Desired amount 700 kg	Desired amount 200 kg	Desired amount 100 kg
	Obtained amount, kg	Obtained amount, kg	Obtained amount, kg
1	711.0	185.5	106.9
2	710.4	185.9	107.9
3	708.6	185.9	106.4
4	709.4	188.8	106.0
5	705.8	187.8	105.7
6	708.4	186.9	107.4
7	710.8	185.9	106.4
8	707.2	192.6	103.1
9	707.9	184.2	108.7
10	705.4	193.0	104.1
Mean	708.5	187.6	106.3
Standard Deviation	1.97	3.00	1.68
Accuracy (%)	1.57	7.9	8.7
Precision (%)	0.44	2.85	2.97
95% confidence interval for mean (kg)	708.5 ± 1.4	187.6 ± 2.1	106.3 ± 1.2

gredient were always higher than the desired amounts of 700 and 100 kg, respectively. These errors appear to be due to errors in setting microswitch number 1 and microswitch number 2. This is so since the amount obtained for microswitch number 3 in the cumulative ingredient tests were relatively correct at 1000 kg (see Table 7).

6.8.2 Precision test for desired ingredient ratio of 700, 200 and 100 kg

Run number 4 of the tests for setting the microswitches for ingredient ratios of 700, 200 and 100 kg was selected for ten replications to determine the precision of the microswitch settings. The results are shown in Table 9. The precisions of the amounts obtained were 0.44, 2.85 and 2.97 percent for ingredients 1, 2 and 3, respectively. The standard deviation of the second ingredient was 3.0 kg which appears relatively high. It would appear as if repetition number 8 and 10 contributed significantly to this high standard deviation.

6.9 Results of testing for effect of varying ambient temperature

Timoshenko (1955) presents methods for the deflection analysis of curved bars. Following the methods described by Timoshenko (1955) the force control device was analyzed for deflection. An approximate solution was obtained through the use of a Gaussian integration on a computer. The results were in the form of a stiffness (load/deflection). The effect on the stiffness of changes in the ambient temperature were investigated. The stiffness is affected by changes in dimensions and physical properties due to temperature changes (Beckwith and Buck, 1969). Changes in stiffness will be reflected in the loads required to trip the microswitches. The predicted effect on ingredient amounts has been plotted in Figure 6.3. Figure 6.3 also graphs the results for the amount of each ingredient obtained experimentally.

There were five runs made at each different ambient temperature for the ingredient ratios of 500, 300 and 200 kg as described in section 5.5. The average obtained amounts for each ingredient at each temperature are shown in Table 10.

The predicted amounts showed linearly decreasing amounts as the temperature increased. The variation in ingredient amounts due to temperature change was calculated and was found to be the same percentage for each ingredient. The variation in amount was -0.026 percent of the desired amount for each degree (Celsius) increase (based on the assumption that the obtained amount equals the desired amount at 20°C).

Experimental results for the second ingredient and the third ingredient showed a roughly uniform decrease in the amounts obtained with increasing temperature. These results agree qualitatively with the results of the analytic prediction that there will be a reduction in the stiffness of the force device with increasing temperature. But the experimental results for the first ingredient (500 kg) showed a trend of increasing amounts for increasing temperature

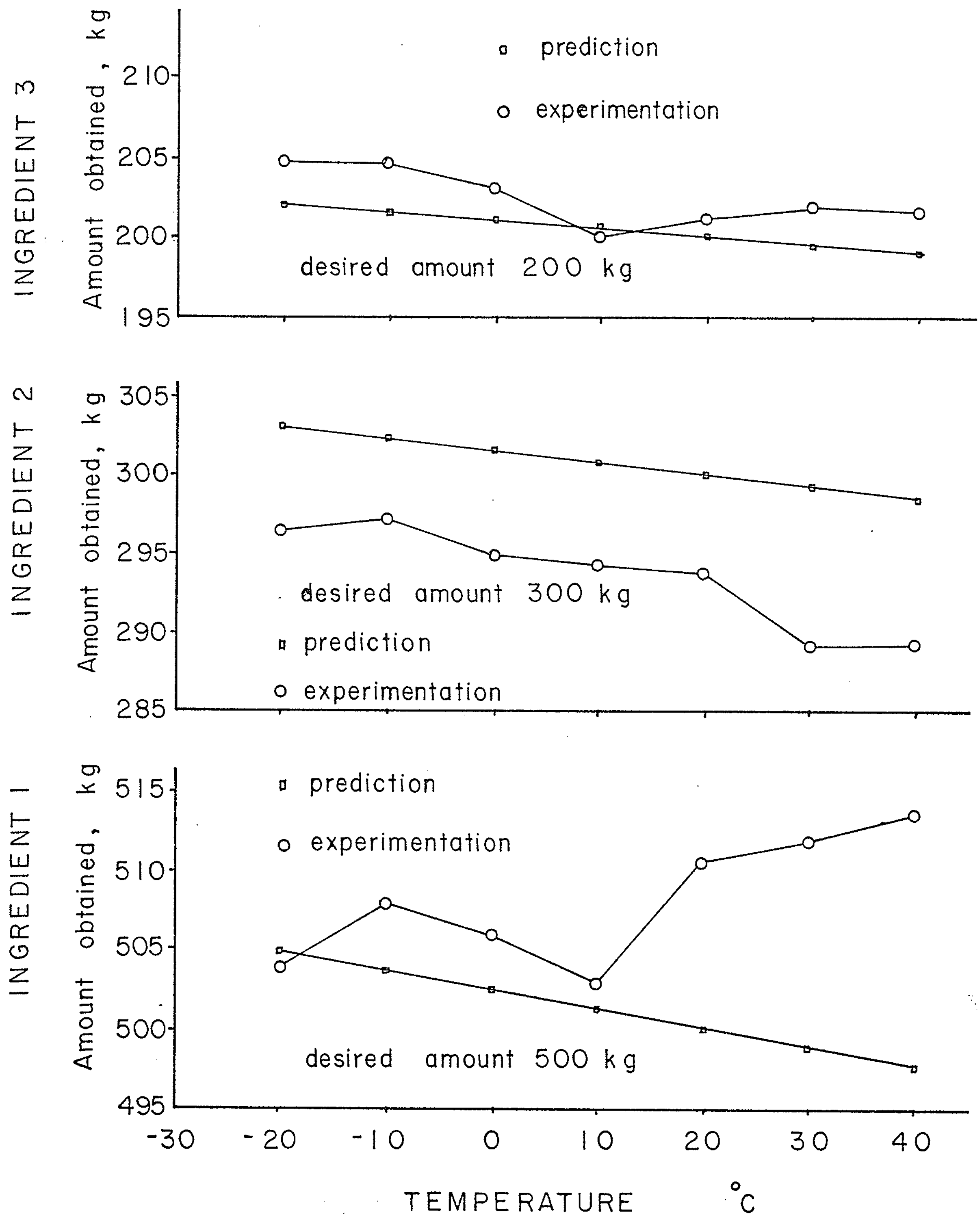

Figure 6.3 Effect of Temperature change on amount of ingredient obtained experimentally and by analytic prediction.

Table 10 Effect of variation in ambient temperature on microswitch settings for ingredient ratio of 500, 300 and 200 kg (Averages for 5 replications)

Ambient Temperature °C	Ingredient 1 kg	Ingredient 2 kg	Ingredient 3 kg
-20 ± 0.7	503.9	296.3	204.9
-10 ± 0.9	507.8	297.0	204.6
0 ± 1.0	505.9	294.8	203.0
10 ± 1.0	502.9	294.2	200.2
20 ± 0.5	510.6	293.6	201.1
30 ± 0.4	511.9	289.0	202.0
40 ± 0.4	513.5	289.0	201.6

while the analytic prediction was for a lower amount at higher temperature. This could perhaps be explained as a temperature effect on microswitch number 1 that was greater than the temperature effect on the deflection beam. If the open ends of the beam moved inward at higher temperatures, the required deflection to activate microswitch number 1 would have been automatically increased.

6.10 Compression loading of the compression Model X force control device

The loading of the holding tank on a portable grinder-mixer was simulated in order to test the compression Model X force control device. The effect of loads applied uniformly around the center of the simulation model and also the effect of off-center loading were investigated. The loading was simulated on a model rather than in a real portable grinder-mixer since (1) a grinder-mixer was not available and (2) in a real grinder-mixer with feed (or wheat) for loading it would have been difficult to determine the exact location of the off-center load.

The model consisted of a 7.6 cm x 6.4 cm x 1.0 cm wide flange beam 165 cm long. One end was supported on a knife edge and the other end was placed on the ball bearing of the compression Model X force control device equipped with a dial gauge. The span length was 150 cm. The load was applied at the center (see Figure 6.4). In the model the beam was initially horizontal to simulate a grinder-mixer that was leveled before any readings would be taken. The

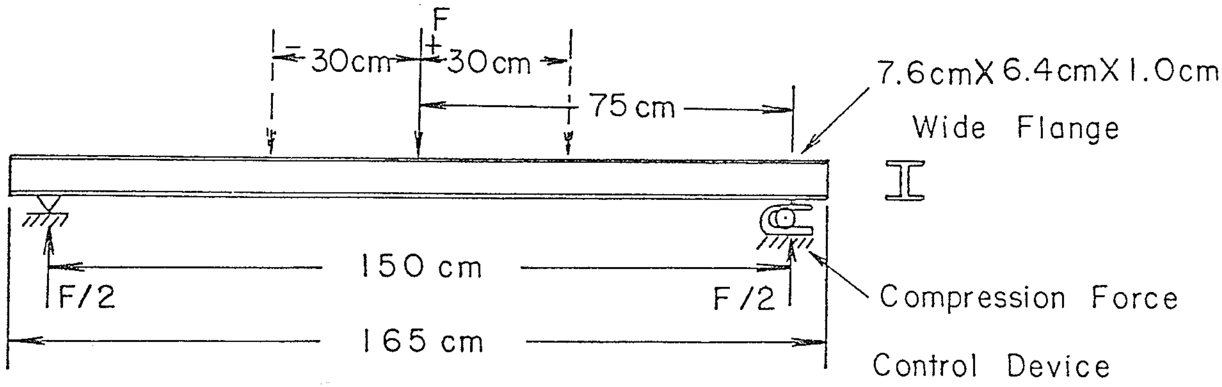

Figure 6.4 Model study of compression force control device

load (F) was applied by a Baldwin Tate-Emery testing machine Model PTE 144 with 15 000 kg capacity and 0.2 percent accuracy of reading.

Figure 6.5 shows the relationship between the applied load on the testing machine compared to the dial gauge reading for three positions of the applied load (midspan, +30 cm and -30 cm).

The simulated grinder-mixer hopper load as indicated by the testing machine load was compared to the calculated hopper load determined from (i) the dial gauge reading, i.e., two times the dial gauge reading and (ii) the calibrated dial gauge reading, i.e., 1.8989 (dial gauge reading) - 0.849 kg. The results are shown in Table 11.

The error due to calculating the hopper load from the dial gauge reading could be determined by

$$\text{Accuracy (percent)} = \left[\frac{\begin{array}{l}\text{Load calculated} \\ \text{from dial gauge}\end{array} - \begin{array}{l}\text{Actual} \\ \text{load}\end{array}}{\text{Actual load}} \right] 100$$

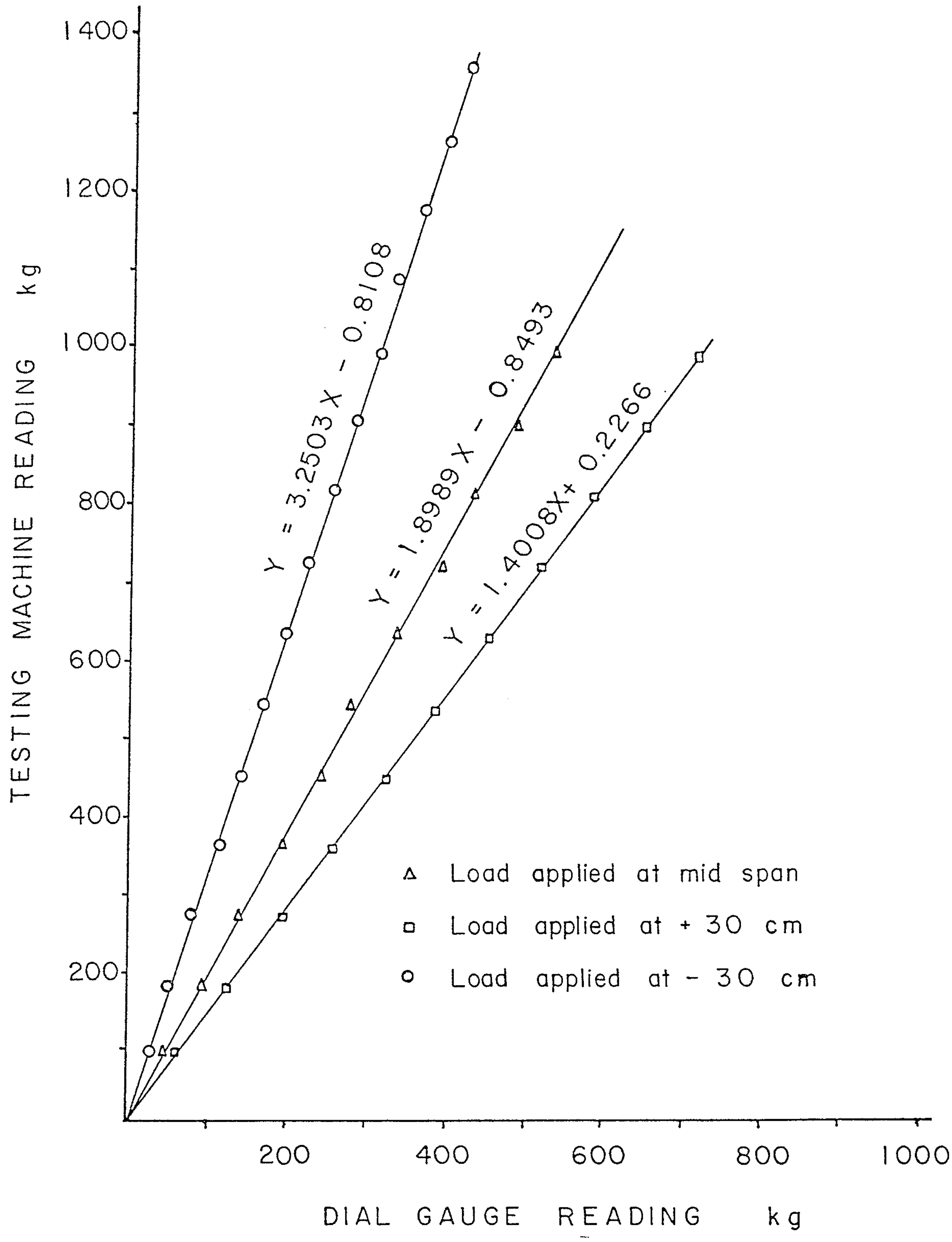

Figure 6.5 Relationship of testing machine loading and loading indicated on dial gauge for three loading positions(Grinder mixer simulation)

Table 11 Simulated grinder-mixer load as calculated from the dial gauge compared to the actual load

Calculated Hopper Load		Actual Simulated Hopper Load		
2(DG), kg	1.8989(DG), kg	load at center	load at +30 cm	load at -30 cm
		Testing Machine, kg	Testing Machine, kg	Testing Machine, kg
200	190	189	140	324
400	380	379	280	649
600	570	569	420	974
800	760	759	560	1299
1000	949	949	701	1624
1200	1139	1138	841	1949
1500	1424	1423	1051	2437

In practical applications the calculated load would be two times the dial gauge reading since it would be assumed that the load was on center. The linear relationships as shown in Figure 6.5 were used in the calculation of the accuracy. The intercept of the equation was small enough to be neglected in the calculation of error. When the load was applied on center, the accuracy was 5.3 percent of reading when the load was calculated as twice the dial gauge reading. This error can be eliminated by using the calibration curve to calculate the load. For the +30 cm off-center load the accuracy was 42.8 percent and for the -30 cm off-center the accuracy was 38.5 percent. These results indicate that if the loading is off-center, appreciable error will occur. In use, the distance off-center would not be known and therefore the calibration curve could not be used.

6.10.1 Precision of microswitch setting on the compression Model X force control device

The four microswitches were set for on-center loads of 96.0, 191.5, 378.2 and 955.9 kg, respectively (based on the dial gauge reading). Three positions of the load were used for the precision test (mid span, +30 cm and -30 cm). Five replications were made for each position of the applied load. Table 12 lists the results of the precision test of microswitch activation on the compression model force control device.

The precisions for microswitches 1 through 4 were

Table 12 Precision test of microswitch activation on compression model force control device

run	desired amount 96.0 kg	desired amount 191.5 kg	desired amount 478.2 kg	desired amount 955.9 kg
	amount obtained, kg	amount obtained, kg	amount obtained, kg	amount obtained, kg
1	94.8	186.8	478.2	967.8
2	94.8	186.8	478.2	969.3
3	93.6	183.1	475.8	969.3
4	91.2	183.1	475.8	969.3
5	92.4	183.1	475.8	969.3
6	92.1	187.7	477.4	968.0
7	88.9	184.4	477.4	963.1
8	87.3	184.4	477.4	964.8
9	88.9	184.4	477.4	964.8
10	88.9	184.4	477.4	964.8
11	91.6	188.6	476.8	956.2
12	90.9	185.2	471.2	956.2
13	90.9	185.2	467.7	956.2
14	90.9	185.2	474.7	956.2
15	94.4	181.7	467.7	956.2
Mean	91.4	184.9	475.3	963.4
Standard Deviation	2.3	1.9	3.5	5.6
Accuracy (%)	9.06	5.12	2.20	1.40
Precision (%)	4.48	2.00	1.60	0.75

4.48, 2.00, 1.60 and 0.75 percent, respectively, regardless of the load position while the accuracies were 9.06, 5.12, 2.20 and 1.40 percent, respectively, for the same ratio. This presents a good illustration of the fact that accuracy and precision are not always the same, i.e., good precision does not necessarily mean good accuracy.

CHAPTER VII

CONCLUSIONS

1. The feasibility of utilizing the force control switches for automation of feed ration ingredient proportioning has been demonstrated.

2. At room temperature, the precision of the tension force control device was better than 3 percent when the desired ingredient amounts were 100, 200, 300, 500 or 700 kg. The precision of the compression force control device with on-center loading was better than 5 percent when the microswitch set points were 96.0, 191.5, 478.2, and 955.4 kg.

3. The accuracy in obtaining the desired amounts of each ingredient determined by the tension force control device and the compression force control device depended on the individual settings of the microswitches.

4. Temperature variation did not have a large effect on the amount of each ingredient obtained in the temperature range -20°C to 40°C when using the tension force control device except for the first ingredient where the error was 0.028 percent of the desired ingredient amount for each degree (Celsius) increase.

5. Off-center loading when using the compression force control device gave greatly reduced accuracy. When loaded only 20 percent of span length off-center, the error was up to 42.8 percent.

6. The ingredient amounts as determined by the tension force control device were more accurate than the ingredient amounts determined by the compression force control device.

CHAPTER VIII

RECOMMENDATIONS FOR FURTHER STUDY

1. Further work is required in applying the force control device to portable grinder-mixers.

2. The effect of vibration on the accuracy and precision of the force control device should be studied.

3. The effect of the type of conveyors that convey the ingredients to the weighing hopper should be investigated, i.e. the location of shut-off gates, overrun, etc.

4. A method for accurately setting the micro-switches for each ingredient should be found.

5. The use of the force control switches to control the operation of a mixer where a time delay is required for the mixing operation should be investigated.

6. The application of the force control devices in weighing animal crates should be investigated.

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APPENDICES

APPENDIX 1

Table A.1 Calibration data for the ring dynamometer for the three ingredient ratios at room temperature

Ingredient ratio kg	Regression equation	Correlation coefficient	Average sensitivity kg/V
	$Y = 473.5993\ X - 0.7478$	1	
200:300:500	$Y = 471.6433\ X - 0.1584$	1	472.397
	$Y = 471.9494\ X + 0.1420$	1	
	$Y = 475.0749\ X + 1.1567$	1	
500:300:200	$Y = 474.3703\ X + 0.6783$	1	474.258
	$Y = 473.3293\ X - 0.6985$	1	
	$Y = 474.6037\ X - 1.8030$	1	
700:200:100	$Y = 472.8344\ X - 0.6867$	1	473.130
	$Y = 471.9509\ X + 0.9319$	1	

Y = Net amount in weighing hopper, kg

X = Voltmeter, V

APPENDIX 2

Table A.2 Calibration data for the ring dynamometer for the effect of temperature variation

Test Temperature °C	Regression equation	Correlation coefficient	Average sensitivity kg/V
-20	Y = 472.7492 X +0.5337	1	473.195
	Y = 473.6406 X +0.1785	1	
-10	Y = 473.6552 X -0.1262	1	473.441
	Y = 473.2265 X +1.0409	1	
0	Y = 473.0039 X +0.2051	1	473.326
	Y = 473.6474 X +1.0844	1	
10	Y = 469.7517 X +0.1668	1	471.416
	Y = 473.0805 X +0.0908	1	
20	Y = 471.9279 X +0.0078	1	473.954
	Y = 475.1811 X +0.2581	1	
30	Y = 474.5441 X -0.7470	1	472.502
	Y = 470.4594 X +0.2058	1	
40	Y = 473.8784 X +0.1383	1	472.658
	Y = 471.4379 X +1.5465	1	

Y = Net amount in weighing hopper, kg X = voltmeter reading, V

APPENDIX 3

Capacity of auger conveyors

conveyor	capacity* kg/s
Auger number 1	2.25
Auger number 2	1.50
Auger number 3	1.60

*Average for six tests