International
Fertilizer Industry
Association

ISMA[*] Technical Conference

Helsinki, Finland

3-5 September 1963

[*]In 1982, the name of the International Superphosphate Manufacturers' Associations (ISMA) was changed to International Fertilizer Industry Association (IFA).

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METERING AND CONTROL OF INGREDIENTS FOR MIXED FERTILIZERS

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Introduction

The title of this paper has been interpreted somewhat loosely in order to provide the maximum information on metering and control in the fertilizer industry. For instance, in the granulation process, steam is not an ingredient, but its metering and control are interesting in some respects. Also, sulphuric acid used in superphosphate manufacture and phosphoric acid used in triple superphosphate, etc., are not strictly speaking ingredients, but rather intermediates. However, they have been included because of some special features of interest.

With regard to metering and control of comminuted solids, batch weighing has been excluded as being an entirely separate subject; continuous weighing only is considered. The term "comminuted" is used to cover coarsely crushed, finely pulverised, and granular solids.

The subject matter divides itself naturally into three main sections: the metering and control of:-

A. Gases, including steam.

B. Liquids and Slurries.

C. Comminuted solids.

There is also a General section which deals with accuracy of metering and with problems of control inter-connection for the purpose of proportioning i.e. ratio control of solids and liquids.

GENERAL

1. Proportioning of Ingredients

Proportioning systems reduce finally to ratio control, either as Parallel Ratio control (Shown in Fig. 1a) or Cascade Ratio control (Shown in Fig. 1b)., or a combination. Each of these arrangements has advantages in certain circumstances. Where time lags are important, the parallel ratio system will ensure that all the flows increase and decrease simultaneously. But sometimes one stream is either uncontrollable or unreliable, and yet it is important to maintain a correct proportion between the streams. In such cases the uncontrollable or unreliable stream must be made the master or primary of a cascade ratio system.

Irrespective of the system which is used, interconnection of controls in ratio has an important bearing on the type of primary measuring element which it is best to use, with regard to the relationship between measurement and output signal. Differential pressure primary elements for flow measurement (e.g. the orifice, venturi, flow nozzle) generate an output signal the square root of which is proportional to the rate of flow. In the case of all other commonly used flow metering devices (e.g. variable-area, magnetic, and propoller-type, flowmeters; metering pumps; continuous belt weighers for solids) the signal is linearly proportional to the rate of flow.

In proportioning, it is not possible to couple unlikes, so all signals must be square root or all must be linear. If all the signals are linear, there is no difficulty in coupling them together in any desired ratios (from 3:1 to 0.3:1 is the usual limit for commercial instruments), and origin shift can be incorporated easily. This means that all the flows do not have to start simultaneously from zero. One or more can be made to lead the others by pre-set amounts.

If all the signals are square root, then simple ratio control is all that is practicable, and the range of adjustment is usually

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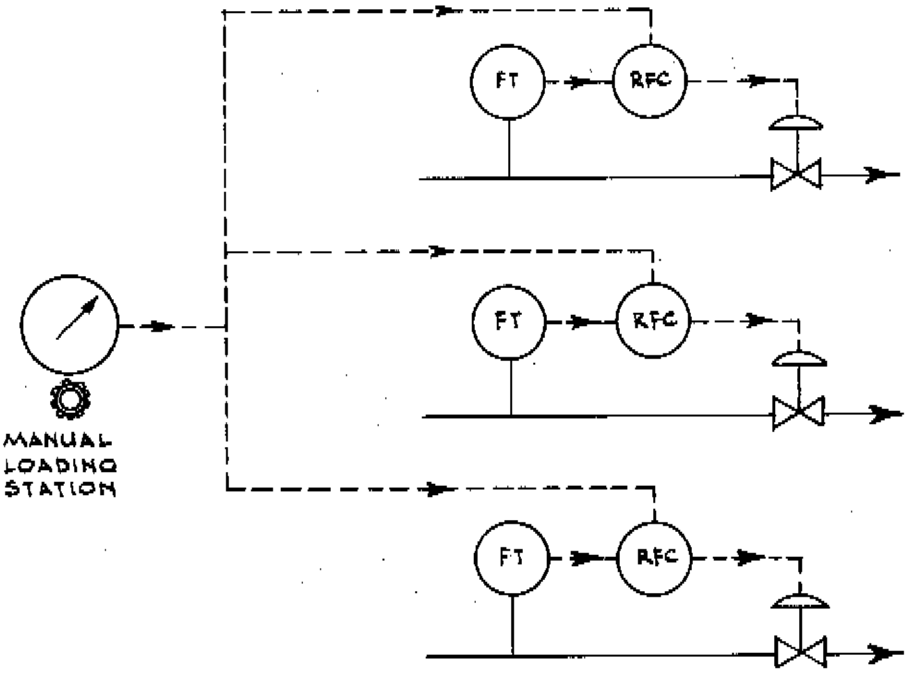

LEGEND

FT - FLOW TRANSMITTER
FC - FLOW CONTROLLER
RFC - RATIO FLOW CONTROLLER

FIG 1(a) - PARALLEL RATIO.

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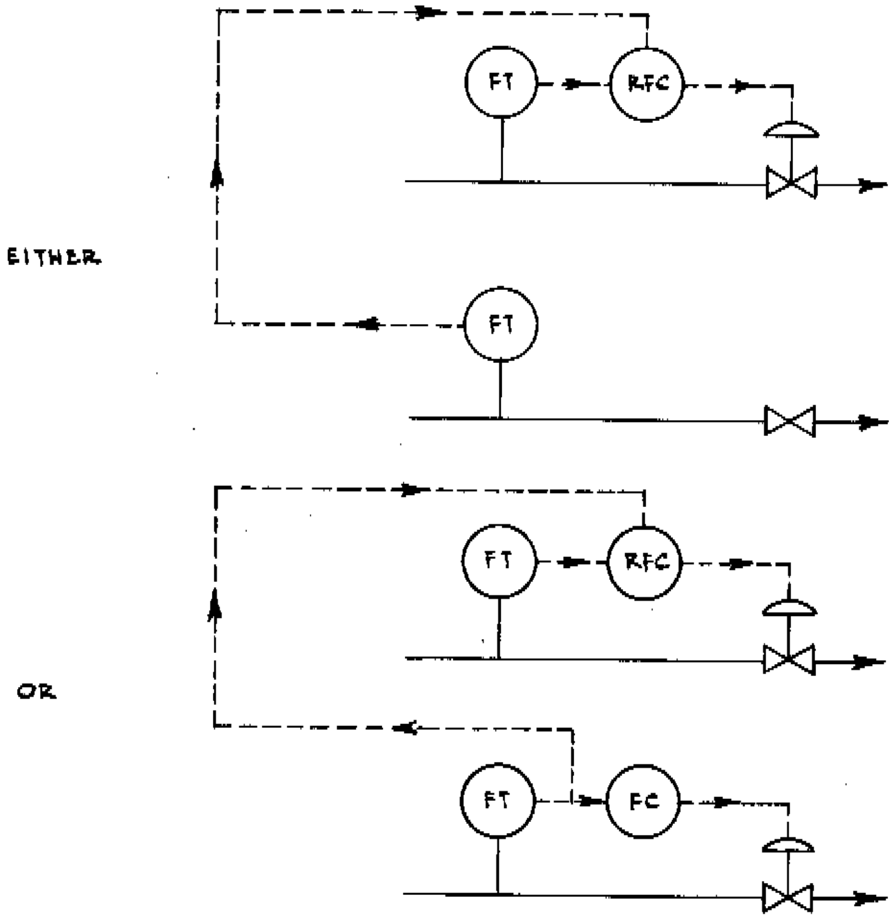

LEGEND

FT - FLOW TRANSMITTER
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RFC - RATIO FLOW CONTROLLER.

FIG 1(b) - CASCADE RATIO.

restricted to 1.5:1 to 0.5:1. Origin shift is impracticable, so that all flows must always start simultaneously from zero.

It is clear that linear signals allow more flexibility in the design of a proportioning system and provide a greater range of ratio adjustment, therefore, in this respect at least, it is preferrable to select primary metering devices having a linear relationship between signal and rate of flow.

Of course, a square root signal can be converted to a linear signal by using a suitable characterised amplifier, commercially available in either pneumatic or electric form. However, this procedure has serious disadvantages. At low flow the amplification is great, as stressed by a prominent instrument manufacturer (Mr. L.S. Yoxall) who has said that square root extraction is a device to enable one to read the low-flow inaccuracies more easily. In other words, the expanded scale at low flows is an apparent, and not an actual, gain in accuracy and readibility. A further point is the effect of such a conversion on the reliability of the system as a whole, and on the ease of checking for errors. The signal converter is a relatively delicate and sensitive piece of equipment, requiring additional checking and calibration.

Therefore, as a general rule, differential pressure primary elements should not be used for flow measurement of ingredients where automatic proportioning is contemplated. Even in the case of manual proportioning, it is not easy for the operator to correlate a miscellany of square root and linear readings. An exception to this rule is the case where simple ratio control is required over a limited range, and all ingredients can be measured most conveniently by differential pressure devices. Another and more common exception is the case where most of the measurements are linear (e.g. continuous belt weighers for solids) but one quantity (e.g. steam) is more conveniently measured by, say, an orifice. This might be because it is a large quantity, or because the normal flow rate must be changed greatly from time to time, an orifice being relatively easy and cheap to change. In such a case it might be worth while to accept the additional complication and low-flow inaccuracy involved in converting this signal from square root to linear.

It should be noted that it is possible to convert a linear signal to a square root signal by a simple, accurate, and reliable mechanism (e.g. a cam) because no amplification is required. But, from the foregoing analysis, it can be seen that the necessity for such a conversion seldom, if ever, arises in proportioning.

2. Accuracy of Metering

Results of actual tests are given later in the paper when dealing with specific examples of measurement of liquid and comminuted solids flows. However, metering accuracy, errors and calibration, require some general consideration. This is an extensive and important subject, inadequately covered in the technical literature. It would be impossible to treat it systemmatically in the present paper, but it was considered worth while to deal briefly, and in an elementary fashion, with a few of the points which, by experience, have been found to cause the most difficulty.

(a) Conventions for sign of error

There are two current conventions for expressing the sign of an error, both of which can be defended logically.

As an example of one convention, suppose that a weighing machine indicates (or is pre-set for) 112 lbs and it actually weighs-out or delivers only 111 lbs. It is usual to express such an error as - 1 lb. Obviously, if a total of 111 lbs of test weights were to be placed on this machine, it would indicate 112 lbs. Thus, in this case, when the actual value or quantity is less than the indicated or pre-set value, the error is called negative, and vice versa. This convention is usually followed for batch and continuous weighers, and fluid quantity meters.

Using the same numerical values, consider a pressure gauge which indicates 112 p.s.i.g. when a true pressure of 111 p.s.i.g. is applied. It is usual to express the error as +1 p.s.i. Thus the convention for expressing the sign of the error is the opposite of the preceding case. This latter convention is normally used for indicators of flow, temperature, and pressure but doubt often arises in the case of a flow-meter with an integrator, or a flow controller set to deliver a certain quantity on a time basis.

In this paper, to avoid doubt, the first convention will be used in all cases, That is, the error will be taken to be that quantity which, when added algebraically to the reading of an instrument or to the indicated or pre-set quantity of a meter or weigher, gives the true or actual value or quantity. Thus, when the true value or quantity is higher than the indicated or pre-set value or quantity, the error is said to be positive. When the true value is less than the indicated or pre-set value, the error is said to be negative.

(b) Quantitative Expression of Errors, or Limits of Accuracy

In the case of flow meters or weighing machines it is usual to express errors (or claim accuracy limits) in terms of percentage of full scale deflection (% F.S.D) i.e. per cent full scale reading. An equivalent way is to express the error or limits of accuracy directly in terms of the measured quantity e.g. a weighing machine may be said to be accurate to ± 2 lbs. at any point on its scale. This method of expression has a considerable effect at low scale readings. For instance an instrument may be claimed to be accurate to ± 2% F.S.D. At one tenth full scale the claimed accuracy is then only within ± 20% of the reading.

In the case of fluid quantity meters of the mechanical type, it is more usual to express the error as a percentage of the quantity actually measured, called "Percent of actual reading" or "Percent of instantaneous reading". This is because such meters cannot be said to have a full scale reading. Other equivalent methods are to give the errors or limits of accuracy of meter factors, or flow coefficients, or in terms of the

$$\text{ratio} \quad \frac{\text{True quantity}}{\text{Meter reading}} \times 100$$

When accuracies are claimed in this way, they should be qualified by restricting the scale range over which the limits apply, or by relaxing the limits at lower readings. Obviously it would be absurd to expect a weighbridge to weigh an airmail letter, but this is what would be claimed by an unqualified statement of accuracy in terms of instantaneous reading.

Misunderstandings frequently arise in respect of expected or claimed limits of accuracy over wide ranges of flow. Our own experience indicates that, with most measuring instruments, there are elements of error which are independent of reading (i.e. constant in % F.S.D.) and other elements which increase with reading (i.e. constant in % instantaneous reading). The relative magnitudes of these depend upon a large number of factors, including the design, construction, installation, maintenance, calibration or prediction, and principle of the instrument. Accuracy claims should take realistic account of these factors.

One notable error which (for instruments with linear scales or charts) remains constant in terms of F.S.D. is the precision with which the scale or chart can be read by eye. For instance, a full-sized circular chart recorder or miniature strip chart recorder has an effective chart width of approximately 4". Then ± 1% of this is ± 0.04", which is easy to read by eye. But if an accuracy of ± 1% of instantaneous reading were expected or claimed down to 1/10"th full scale, this would require the chart to be read to ± 0.004" which is impossible under normal circumstances. The practical limit is certainly not closer than ± 0.01" which is ± 2.5% instantaneous reading at 1/10"th full scale, and any claim better than this is clearly wrong for such an instrument.

Errors which increase with reading are largely caused by incorrect span adjustment, by distortion with increasing loads, and, for example, by errors in orifice coefficients. It should be noted that such errors can be significantly reduced by calibration and are therefore much more serious in predicted instruments (e.g. uncalibrated orifice installations) than in calibrated instruments.

The effect of flow rate upon hysteresis errors varies greatly from one instrument to another. Hysteresis due to lost motion is independent of reading. Hysteresis due to friction often increases with reading.

The variable-area flow meter is subject to special non-linear errors under some circumstances. These will be discussed in Section B of the paper.

It should be noted that limits of error or accuracy have been expressed above as simple arithmetical limits. "Standard Deviation" and similar statistical terms have not been used. This follows the usual practice of instrument manufacturers, and there are reasons for it. It would be very laborious, in an ordinary meter calibration, to carry out sufficient tests for statistical analysis at each rate of flow. Furthermore, it is doubtful if instrument error distribution curves are often "Normal" or Gaussian. Therefore there may be little practical significance in statistical approximations such as ± 3 x Standard Deviation = 99% Confidence limits, and ± 2 x Standard Deviation = 95% Confidence limits. Consequently, we consider that it is best to express meter error or accuracy limits as simple maxima, unless an adequate number of results have been obtained to plot a reliable histogram.

(c) Systemmatic Error

This is the difference (expressed quantitatively in any of the ways discussed above) between the arithmetic mean of a large number of readings and the true quantity.

Systemmatic errors are of no importance as regards quality of automatic control, but of primary importance in costing and accuracy of compounding. They can be subdivided as follows:-

(i) Zero Errors:

Such errors are constant in terms of full scale deflection. They are easily removed by zero adjustment, without the need for calibration. They are not experienced in mechanical and propeller-type fluid quantity meters.

(ii) Span Errors:

Such errors are constant in terms of instantaneous reading. They are found in all types of meters and can be removed only by calibration.

(iii) Non-linearity Errors:

These can be particularly troublesome in the cases of mechanical meters and variable-area flowmeters. For mechanical meters they cannot be removed by calibration and are inherent in the design of the meter and the viscosity and lubricity of the liquid measured. In bad cases, the only way to obtain accurate measurements is to calibrate and use the meter at the same rate of flow.

For variable area flowmeters, calibrations at many points in the flow range can be used to prepare a special scale, or a correction curve for a standard scale. But, if an integrator is fitted, it is usually impracticable to correct this also.

Similar errors are found in orifice and Venturi meters at Reynolds Numbers in the throat below 200,000 to 500,000, depending on the design of the primary element and associated pipeline, and also upon the Reynolds Number in the pipe. (Ref. 1).

(d) Random Error, otherwise known as "Repeatability" or sometimes in America as "Precision".

This is the difference (expressed quantitatively in any of the ways discussed above) between an individual reading and the arithmetic mean of a large number of readings, when the same true quantity is being measured in each case. It should not be confused with "Noise" in the measured variable which is not a metering error but can give rise to errors if the response of the measuring unit is assymmetrical, or if damping is applied to a square root relationship.

Strictly speaking, hysteresis errors are not truly random, but they are usually included under the general heading. This is justifiable because individual readings are usually taken when the flow is increasing and also when it is decreasing.

It is noteworthy that random errors are self-cancelling over a sufficient number of readings, and therefore they should not cause inaccuracy in long-term measurements. But a random error in a single calibration becomes a systemmatic error until the next calibration.

Where automatic control is concerned, random errors (particularly those caused by lost motion and stick-slip friction) can be so damaging in their effect as to prevent any reasonable control.

(e) Total Error, otherwise known as Absolute Error

(The terms "Absolute accuracy" or merely "Accuracy" are also used sometimes).

This is the difference (expressed in any of the previously described ways) between an individual reading and the true quantity. It is thus the sum of the random and systemmatic errors.

(f) Drift

This is a slow change in systemmatic error. It becomes damaging when the rate of change is appreciable in relation to the period between routine checks and calibrations.

(g) Calibration Errors

The calibration apparatus and procedure is subject to all the errors mentioned above. It should be noted that, if calibrations are carried out using the working fluid under working conditions, and as the meter is normally installed, and if the results so obtained are used until the next calibration, then the cumulative error in measurement after a large number of calibrations will be equal to the systemmatic error of the calibration apparatus and procedure alone. The random errors of calibration, and the random and systemmatic errors of the meter will be eliminated.

A. GASES, INCLUDING STEAM

In the metering and control of process gases we have experience only with orifice and variable area meters. (Venturis, flow nozzles etc. used in other parts of our Works are not dealt with in this paper). As primary measuring elements for gases, orifice meters and variable area meters each have advantages and disadvantages. These can be summarised as follows:-

1. Orifice Meters

The orifice plate is a relatively cheap primary element especially in the larger sizes, and it is easily changed to suit an alteration in process requirements. The square root of the output is proportional to the rate of flow which, as previously pointed out, renders it inconvenient for incorporation in proportioning systems. Also the readability of the rate of flow indicator or recorder chart decreases so rapidly at low flows that estimation of flows below $\frac{1}{3}$rd full flow is difficult and below 1/5th full flow it is practically impossible.

In practice the maximum accurate range of a single orifice meter installation may therefore be taken as 3 to 1, although this can be extended to 5 to 1 for less critical measurements. However it is relatively easy and cheap to cover much larger flow ranges by a multiple orifice installation using a single flow transmitter, or by using an interchangeable orifice fitting such as the Daniel. For instance we have a 3 orifice installation measuring and controlling steam flow, the full-scale flows of the orifices being 200, 1,000 and 5,000 lbs/hr. Any one of these orifices can be connected as required to a single flow transmitter and by means of this arrangement it is possible to measure and control flow from 40 to 5,000 lbs/hr.

In such a system, a great deal of care must be taken with the impulse line manifolding to avoid leaks and gas or liquid locks. The impulse lines should not be less than ½" I.D. and should be sloped properly. Good quality plug cocks should be used for isolation purposes.

We have no test data regarding accuracy, but manufacturers usually claim ∓ 2% of full scale reading, providing that temperature and pressure and density are constant. We consider that this is probably over-optimistic for normal plant installations, with average maintenance. To attain this degree of accuracy it is necessary that the installation should be very carefully designed in accordance with B.S. 1042 or similar specification, paying particular attention to the runs of straight pipe required upstream and dowstream of the orifice, and to disturbances of flow pattern caused by fittings etc. up-stream. The meticulous design, and space requirements, are further disadvantages of the orifice meter. Another point is that, on pulsating flows, the accuracy of an orifice meter suffers because of root mean square error.

It should be mentioned that we have found differential flow transmitters to be worth the extra expense in all cases where anything more than local flow indication is required.

The dp cell eliminates long impulse lines which must be laid carefully to avoid errors. Such work is always expensive and, with some plant lay-outs, it is almost impossible to obtain a trouble-free impulse line installation.

2. Variable Area Meters.

The only type of variable area meter considered in this paper is the float-and-tapered-tube pattern, in which the differential pressure remains constant, as determined by the float weight and area. Increasing flow causes the float to rise up the tube, thus providing a greater annular area for flow. Theoretically the range of such an instrument could be infinite, but the float would obviously jam in the tube at zero flow, and the annular clearance tolerance would be critical at very low flows. Therefore, for practical reasons, the range of most of these instruments has been standardised at 10 to 1.

The main advantage of such meters is that the float position (which provides the flow reading) varies linearly with flow. To be precise, the relationship is not exactly linear in that the scale closes up slightly at high flows. This affects the scales of indicating meters but, in the usual magnetic-coupled type of transmitter, the slight non-linearity is removed by correction cams or linkage, and the output signal is in fact a linear function of flow.

The linear relationship carries with it the following advantages:-

(a) The scale can be read easily down to its minimum value of 1/10 full flow, and it is far more straightforward for an inexperienced operator than a square root scale.

(b) For pulsating flows, the mean of the output signal gives an accurate measure of the mean flow.

(c) The signals can be incorporated conveniently into an automatic proportioning system and can be correlated easily with other linear signals either automatically or by the process operators.

A further considerable advantage is that there are no requirements for straight pipe runs up-stream and down-stream of the meter.

The chief disadvantage of the variable area flow transmitter, particularly in the larger sizes, is capital cost. Also, the range of such a meter can be changed only within small limits by alteration of the float weight. An appreciable change of range requires a complete new meter. A point which should be watched is the possibility of damage to the float and magnet assembly caused by suddenly imposed high flows. The float-stop mechanism should be mechanically robust and, even then, sudden flow overloads should not be permitted.

In the measurement of gas flows only, there is the further difficulty of float-bounce. This occurs because the float-weight and gas volumes in the pipe lines up-stream and down-stream form an almost undamped system having inertia and spring-rate. Under certain circumstances the bounce can be violent and self-sustaining and can cause mechanical damage and render measurement impossible. The probability of float-bounce is reduced by using a larger tube and float creating less differential pressure across the float, but this is expensive. Another method is to fit a restriction or control valve or pressure reducer in the pipe line immediately adjacent to the meter. By this means the system can often be tuned off resonance. In the worst cases a special damping dashpot must be fitted to the lower extension rod of the float assembly.

Regarding accuracy, we have a considerable amount of test data for variable area meters calibrated on water (which will be summarised in the following section), but none on gas measurement. However, we consider it safe to assume that, for gas flow measurement, the variable area meter is at least as accurate as the orifice meter at high flows, and much better at low flows.

3. Automatic Flow Control of Gases

No special problems are presented in the automatic control of gas flows, but where possible, we make use of critical pressure drop to avoid the necessity for an automatic controller. Where the pressure drop across a control valve exceeds half the absolute up-stream pressure, the flow through the valve will be dependent only on the valve opening and on upstream pressure, and independent of down-stream pressure variations. Thus, if the up-stream pressure is controlled by a simple pressure regulator, the flow may be set by the valve and it will remain steady without automatic control.

We have found that the maximum flow range for good control for a single equal-percentage control valve is approximately 20 to 1. This allows a margin above and below the range for effective control. Where control over a greater range is required (as in the example previously given of 40 to 5,000 lbs/hr steam) it is necessary to use more than one valve. The effective control range of valves having less favourable characteristics than equal-percentage will naturally be less than 20 to 1, but we have no actual figures for such types.

B. LIQUIDS AND SLURRIES

In general, for the metering and control of process liquids, we use only variable area meters or magnetic flowmeters, and for slurries we use the latter only. We do not use orifice meters, both because of the square root output-to-flow relationship, and also because of the difficult nature of most process liquids in the fertiliser industry. Those difficulties include corrosion, erosion, deposits, and freezing at ambient temperatures. In some cases it would be possible to use orifice meters with appropriate purging or sealing arrangements, but these are liable to be troublesome in practice, and we prefer types of meters which do not require them.

(For special case of quantity measurement of liquid ammonia, we use turbine-type meters which will be mentioned separately at the end of this Section).

1. Magnetic Flowmeters

The magnetic flowmeter is, by now, a well-known and well-tried type, available from several different manufacturers in a wide variety of sizes, tube linings, and electrode materials.

In principle it is based on Faraday's law of electromagnetic induction, where a conductor of length L moving in a magnetic field of strength H with a velocity V perpendicular to the field generates an e.m.f. $E = k. LHV$. In modern designs, the field is generated by an A.C. electromagnet enclosing the flow tube (non-conducting or with a non-conducting lining) in which are set two insulated electrodes to sense the e.m.f. generated. The moving conductor is the element of liquid passing between the electrodes, and V is the average velocity of the liquid. Thus the meter measures purely the total volumetric flow, even when suspended solids are present, and it is insensitive to most kinds of disturbance to the flow-pattern, so that straight lengths of pipeline up and down stream are not required.

These meters have been described very fully and efficiently in the technical literature (Refs. 2,3) therefore no further general details will be given here. Attention will be confined to the advantages and disadvantages of the magnetic meter as compared to the variable-area type, for the measurement and control of fertilizer process fluids and slurries.

2. Comparison of the Magnetic Flowmeter with the Variable-area-type

Disadvantages

(a) Greater capital cost.

A complete flow recorder - controller assembly of the magnetic type is roughly twice the price of the corresponding variable area type.

(b) More complex maintenance.

The magnetic flowmeter is necessarily a far more complex piece of equipment and, if it develops a fault, it may require skilled and trained maintenance, with the necessary test equipment. This factor becomes important when it is proposed to install one or two magnetic meters in a place remote from the manufacturer's service organisation.

Advantages

(a) Greater accuracy initially, and greater sustained accuracy when measuring usual fertilizer process liquids (see later).

(b) Greater flow range.

For a single meter the flow range may be extended to 100 to 1, covering this in 2 or 3 steps by range-change switches. Alternatively, a continuous range adjustment may be provided. Thus it is sometimes possible to make one magnetic meter perform a duty for which two variable-area meters would be required.

(c) Not liable to mechanical damage by sudden flow overloads.

This is particularly important on many fertilizer liquid streams where periodic cleaning must be carried out by purging and flushing. Vigorous flushing is sometimes necessary for good cleaning, and this can cause damage to the float assembly of variable-area meters.

(d) Not damaged or blocked by large solid particles which may find their way accidentally into the fluid stream.

(e) Better corrosion resistance.

The only parts in contact with the fluid are the tube lining and the electrodes. We have found that, if the former is Teflon (P.T.F.E) and the latter are pure platinum, there is complete corrosion resistance to all the fertilizer liquids we employ.

(f) Unaffected by erosion.

We have found no evidence of erosion, even after prolonged service on phosphoric acid/gypsum slurries. As will be discussed later, the accuracy of variable-area flowmeters is strongly affected by erosion.

(g) Unaffected by deposits.

From Ref. 2 it can be seen that the accuracy would be affected by a thick deposit of material having a lower electrical conductivity than the measured liquid. However, we have detected no decrease in accuracy caused by the deposits encountered when measuring wet-process phosphoric acid.

(h) Unaffected by variations in viscosity or density.

The magnetic meter measures pure volumetric flow, regardless of viscosity or density changes.

In our experience the advantages of the magnetic flowmeter far outweigh its disadvantages, and we are tending more and more to the use of this type of meter, at least for all difficult process liquids.

2. Accuracies of Magnetic and Variable-area Flowmeters

(a) Calibration equipment and procedure

Calibrations are usually carried out with the meter in situ, and a simple procedure is adopted. A tared drum is mounted on a transportable weighing scale which has itself been calibrated by test weights. A dock water or fresh water line is connected to the pipe system in which the meter is mounted, and flow is established at the desired rate. Since all flowmeters which we calibrate in this way are part of an automatic control loop, it is easy to ensure a steady flow. After passing the meter and control valve, the water flows through a flexible hose to drain, adjacent to the drum and weigh-scale.

A stop-watch is started manually, and simultaneously the hose is switched into the drum, also manually. After a period of not less than 60 seconds (shorter periods lead to excessive timing errors), the hose is again manually switched to drain, the stop-watch is stopped, and the water in the drum is weighed. Meanwhile the rate of flow has been read directly from the local indicator scale of the flow transmitter so that transmitter and receiver errors are not included. (These may be checked at any time by static calibration). Duplicate runs are usually carried out at each rate of flow.)

In the case of variable-area meters, the manufacturer's conversion curves or conversion factors are used to convert the weighed water flow-rate to the liquid flow units of the meter scale. In the case of magnetic flowmeters, the conversion is carried out purely on a volumetric basis.

Although the calibration equipment and procedure is very simple, we consider the accuracy to be sufficient for Works purposes. We estimate the weighing error to be within

(a) systematic error ± 0.1% F.S.D. of the weighing scale
(b) random " ± 0.1% " " " " "

making the limits of total weighing error ± 0.2% of the full scale of the weighing machine.

As regards timing errors, surprisingly accurate results can be obtained by skilled and practised operators, providing that a good 1/10th second stop-watch is used, and that one man operates both the stop-watch and the hose. Our experience indicates that, under these conditions, the error is within ± 0.2 second, which is entirely random since the stop-watch itself can be regulated exactly. Such accuracy may seem improbable at first sight, but it must be remembered that similar errors at the beginning and end of each run are self-cancelling.

These error estimations should be taken into account when deciding the optimum duration of each test. With the average size of the flowmeters in which we are interested, the maximum convenient duration of test at full flow is about 60 seconds. This gives a weight of water of the order of 400 lbs. which is about the maximum for a transportable weigh-scale and standard drum.

Assuming then, for a meter test at full flow, the duration is 60 seconds and the weigh-scale is effectively fully loaded, the combined total error limits of calibration weighing plus timing will amount to ± 0.5% of the measured mass flow rate. This is equivalent to ± 0.5 on the calculated meter error when the latter is expressed in % instantaneous reading. Under these circumstances if, in a single test, the meter error has been calculated as, say, - 1.1% instantaneous reading, it ought really to be expressed as (- 1.1 ± 0.5) % instantaneous reading.

When calibrating the same meter at lower rates of flow, it is desirable to reduce the amount of water collected, in order to maintain the calibration error limits constant at ± 0.5. In our case this is achieved if we reduce the water collected at 1/10th full flow to 40-50% of the weight collected at full flow, with proportionate reductions at intermediate flows. The duration at 1/10th flow will therefore be four to five times longer than at full flow. Thus the increase in percentage weighing error is compensated by the reduction in percentage timing error.

It should be pointed out that the above estimates refer to limits of total errors in individual calibration tests.

In practice, the spread of results on successive tests at the same meter setting indicates that we are usually well within these limits and probably as close as ± 0.25% for the average of our normal duplicate tests.

Any worth-while improvement in calibration accuracy would involve <u>either</u> an increase in the number of tests at each flow-setting (taking averages and thereby eliminating random error, leaving only the low systematic error of a good weigh-scale), <u>or</u> the use of much more elaborate calibration equipment comprising a permanently installed test-quality weighing machine and tank, and an automatic timing and flow-switching system.

(b) Flowmeter tests and comparisons

Table I gives the results of typical works calibrations of variable-area flow transmitters in good condition. The flowmeters have stainless steel metering tubes and upper float extension rods which house magnet assemblies. These move in non-magnetic extension tubes and the magnets are followed externally by follower yokes which are connected mechanically to flow indicating pointers and to pneumatic transmitters. At one period, Meter A12728 was damaged mechanically and the second calibrations were carried out immediately on its return from the manufacturer. The normal duty of the meters is flow measurement and control of ammonium nitrate solution, 1.38 S.G., working temperature 110°C to 115°C.

Unfortunately the duration of the tests at the lower flows was not increased, as recommended in the previous section. Therefore, making the same assumptions as before regarding weighing and timing errors, the calibration errors for single tests at minimum flows could be as great as ± 2.3% of measured flow rate. For example, the error figures at minimum flow for the first meter could be (4.0 ± 2.3) % Instantaneous Reading, corresponding to (0.4 ± 0.2) % Full Scale Deflection. (The actual figures should be much better because they represent the mean of duplicate tests.) With this reservation, Table I is of interest in that it shows that these meters, when calibrated on water, are substantially within the manufacturer's guaranteed limits of accuracy; in this case ± 2% F.S.D. At the lower flows they are very well within.

The characteristic non-linearity errors of this type of meter are present but are not excessive because the meters were in good condition when tested. When a variable area meter suffers erosion or corrosion of the float, there are positive errors over the whole flow range, becoming greater at lower flows. But erosion and corrosion of the flow-tube can also take place, and this is particularly troublesome when the meter is on flow-control duty, at a steady flow rate for long periods. The tube is eroded preferentially at the annulus between float and tube, and a positive error develops at this point on the scale.

In Table II, three different types of flowmeter are compared directly. The calibrations were carried out by passing the same flow of water through all the meters in series, noting their scale readings simultaneously, and weighing the water as previously described. The glass-tube flow indicator is an ordinary 10" scale variable area meter, graduated by the manufacturer directly in lbs/hour of water, and normally used for water flow indication. The metal-tube flow transmitter is of the same type as reported in Table I, and normally used for the same duty, i.e. measurement of 1.38 S.G. ammonium nitrate solution at 110°C to 115°C. The magnetic flowmeter was an ordinary commercial product, in this case with a stainless steel metering tube, Vulcoferran lines, and fitted with stainless steel electrodes. It is normally used for flow measurement of the same hot ammonium nitrate solution.

It can be seen that the results obtained from the glass-tube flow indicator and the magnetic flowmeter are very good.

The metal-tube flow transmitter is suffering from a zero error of about 250 lbs/hr. If the necessary correction is made arithmetically, it will be apparent that the results of the metal-tube instrument would then be as good as the other two. A fault of this kind would normally be discovered by routine calibration, and rectified. Therefore, from the results in Table II, the magnetic flowmeter would seem to have no advantage in accuracy over the variable area type.

However, we had reports from most of our Works that, although their variable-area flow transmitters were reasonably accurate when calibrated on water, there were serious discrepancies between indicated flows and product analyses when the meters were handling hot ammonium nitrate solution as a fertiliser ingredient. We have no equipment for calibrating the meters on the process liquid under working conditions. For practical reasons connected with size and length of steady runs, the stock tanks would not provide sufficiently accurate results. We therefore decided to compare a metal-tube variable area meter with a magnetic meter by passing the same flow of process liquid through both in series.

Table III gives the results of this experiment. The two meters concerned are the meters reported in Table II and they were in exactly the same condition for the two series of tests, except for the flowing liquid. No corrections have been made for the water-calibration errors reported in Table II. It can be seen that there are serious and non-uniform discrepancies between the two meters at all points on the flow scale. Zero correction of the variable-area meter would only slightly improve the situation.

Except for a slight increase in diameter of the flow tube due to thermal expansion (a factor easily calculated and allowed-for), there would seem to be no theoretical reason why the reading of the magnetic meter should change on process liquid at 110°-115°C. as compared to water at 15°C. On the other hand, a rise in temperature of about 100°C must cause expansion and distortion errors in a variable-area meter, bearing in mind the annular metering orifice, and the magnet and follower system. In this particular case we do not consider that viscosity is an important factor.

The results in Tables II and III are a strong argument for calibration of meters under actual working conditions of process liquid and temperature. Since we have no facilities for such calibrations, we can only make the assumption (which we consider theoretically reasonable in this case) that the magnetic meter reproduces its water calibration accuracies on process liquid, whereas the variable-area type does not. So far, this assumption is borne out by agreement of magnetic flowmeter readings with product analyses and stocks.

Table IV gives the results of water calibration of a twin-range magnetic meter, normally employed on flows of hot ammonium nitrate solution. The linearity is good on both ranges but the meter requires electrical adjustment, particularly in respect of zeros on both ranges.

Table V represents the water calibration of two meters which normally measure 1.84 S.G. sulphuric acid at ambient temperature. These meters are of a different make to those previously dealt with. They have stainless steel flow tubes with Teflon lining and pure platinum electrodes and are similar to the meters we employ to measure and control phosphoric acid/gypsum slurry flows. The "Y Side" meter shows the typically good results we expect from this type of meter. The electrical calibration of the "X Side" meter is at fault, and this test shows how necessary it is to carry out flow calibrations on any meter whose accuracy is really important.

4. Measurement and control of wet process phosphoric acid and phosphoric acid (gypsum slurries)

We carried out trials on a number of magnetic flowmeters in order to find one type of meter capable of measuring all streams on our phosphoric acid plant. This was desirable for reasons of interchangeability and spares. The streams included phosphoric acid/gypsum slurry feeds to the filters at 78°C, and filtered phosphoric acid at various strengths from 22% to 50% and from 78°C to ambient temperature.

We could not use glass flow tubes because of the presence of fluorine, so we tried Chemidus (unplasticised PVC) tubes, realising that the temperature might prove to be too high. Unfortunately, this was the case. The tubes distorted and leakage took place at the electrodes in 3 to 4 months. Therefore we had to use stainless steel tubes with an insulating lining. The following linings were tried:-

(a) <u>Kel-F</u>

This gave no trouble and was clean when removed after 6 months' service on slurry. However it is a very thin, hard, lining and was eroded almost completely through in several places.

(b) <u>Rubber</u>

This gave no trouble but scaled-up badly.

(c) <u>Teflon</u>

Initially these linings gave a great deal of trouble with leakage of acid at the electrodes, resulting from creep of the Teflon. The manufacturers solved this problem with modified electrode design and assembly. Afterwards the Teflon linings were completely satisfactory, and are now in general use. They remain clean after 6 months or more in service, except for a slight black coating which can be wiped away easily, and which does not affect the accuracy.

Regarding electrodes, we found that the only generally satisfactory material is pure platinum.

TABLE 1

Variable-Area Flowmeter Calibrations

Flowmeter Particulars	Flowmeter reading in lbs/hr. liquid 1.38 S.G.	Actual weight of water delivered in 1 min.		Equivalent in lbs./hr. liquid of 1.38 S.G.	Error		
		Dock water	Fresh water		In lbs/hr. liquid 1.38 S.G.	In % Full Scale Deflection	In % Instantaneous Reading
A.12728	2,000	30.5		2,080	+ 80	+ 0.4	+ 4.0
early test	4,000	58.5		3,880	- 120	- 0.6	- 3.0
Full Scale	6,000	88.5		5,900	- 100	- 0.5	- 1.7
= 20,000	8,000	120.5		8,030	+ 30	+ 0.15	+ 0.3
lb/hr.liquid	10,000	149.5		9,960	- 40	- 0.2	- 0.4
1.38 S.G.	12,000	179.0		11,940	- 60	- 0.3	- 0.5
	14,000	209.5		13,970	- 30	- 0.15	- 0.2
	16,000	237.5		15,830	- 170	- 0.85	- 1.1
	18,000	263.0		17,520	- 480	- 2.4	- 2.7
	20,000	294.0		19,600	- 400	- 2.0	- 2.0

/Continued.......

TABLE 1 (Continued)

Flowmeter Particulars	Flowmeter reading in lbs/hr. liquid 1.38 S.G.	Actual weight of water delivered in 1 min.		Equivalent in lbs./hr. liquid of 1.38 S.G.	Error		
		Dock water	Fresh water		In lbs./hr. liquid 1.38 S.G.	In % full scale Deflection	In % Instantaneous Reading
A.12728	2,000	31.25		2,084	+ 84	+ 0.4	+ 4.0
after repair	4,000	61.0		4.070	+ 70	+ 0.35	+ 1.7
by the manu-	6,000	91.0		6,070	+ 70	+ 0.35	+ 1.2
facturers	8,000	117.5		7,830	- 170	- 0.85	- 2.1
	10,000	148.5		9,900	- 100	- 0.5	- 1.0
	12,000	177.0		11,800	- 200	- 1.0	- 1.7
	14,000	206.0		13,720	- 280	- 1.4	- 2.0
	16,000	235.0		15,650	- 350	- 1.8	- 2.2
	18,000	268.0		17,850	- 150	- 0.75	- 0.8
	20,000	296.0		29,700	- 300	- 1.5	- 1.5
Boston Works	2,000		30.5	2,085	+ 85	+ 0.85	+ 4.2
Full Scale	4,000		58.0	3,970	- 30	- 0.30	- 0.75
=,10,000	6,000		85.5	5,850	- 150	- 1.5	- 2.5
lbs./hr.liq.	8,000		117.25	8,020	+ 20	+ 0.2	+ 0.25
1.38 S.G.	10,000		147.5	10,100	+ 100	+ 1.0	+ 1.0

TABLE II

Comparison of Magnetic and Variable-area meters on water flow calibration

Weighed water rate in lbs/hr.	Glass-tube variable-area flow indicator		Metal-tube variable-area flow transmitter		Magnetic Flowmeter		Approximate percentage full scale reading for all instruments.
	Scale Reading in lbs/hr. water	Error in % instantaneous Reading	Scale Reading converted to lbs/hr. water	Error in % Instantaneous Reading	Scale Reading converted to lbs/hr. water	Error in % instantaneous Reading	
3,077	3,000	+ 2.6	2,760	+ 11.0	3,020	+ 1.9	18
5,969	6,000	- 0.5	5,780	+ 3.3	5,900	+ 1.2	36
9,020	9,000	+ 0.2	8,750	+ 3.1	8,920	+ 1.1	54
12,036	12,000	+ 0.3	11,780	+ 2.2	12,000	+ 0.3	72
13,935	14,000	- 0.5	13,660	+ 2.0	14,010	- 0.5	84

TABLE III

Comparison of Magnetic and Variable-area meters on Process Liquid under working conditions

Flow in lbs/hour liquid of 1.38 S.G. at 110° to 115°C, as indicated by:-		Error of variable-area flowmeter assuming magnetic flowmeter is correct		
Magnetic Flowmeter	Variable area flow transmitter	In lbs/hr liquid 1.38 S.G.	In % Instantaneous Reading	In % Full Scale Deflection (20,000 lbs/hr)
2,900	2,500	+ 400	+ 8.0	+ 2.0
4,000	3,750	+ 250	+ 6.7	+ 1.3
4,900	4,750	+ 150	+ 3.2	+ 0.8
5,790	5,800	- 10	- 0.2	- 0.1
6,760	6,600	+ 160	+ 2.4	+ 0.8
7,860	7,750	+ 110	+ 1.4	+ 0.6
8,690	8,500	+ 190	+ 2.2	+ 1.0
9,660	9,500	+ 160	+ 1.7	+ 0.8
10,310	10,100	+ 210	+ 2.1	+ 1.1
10,760	10,400	+ 360	+ 3.5	+ 1.8
10,900	10,350	+ 550	+ 5.3	+ 2.8
11,100	10,350	+ 750	+ 7.3	+ 3.8
13,660	13,350	+ 310	+ 2.3	+ 1.6
14,080	13,350	+ 730	+ 7.1	+ 3.7
14,500	13,350	+1,150	+ 8.6	+ 5.8
16,480	15,800	+ 680	+ 4.3	+ 3.4

TABLE IV
Twin-range magnetic flowmeter, water calibration

Range	Flowmeter scale reading (percentage scale)	Scale reading converted to tons per hr. liquid 1.38 S.G.	Duration of test in secs.	Actual wt. of water in lbs.	Equivalent in t.p.h. liquid 1.38 S.G.	Error		
						In t.p.h. liquid 1.38 S.G.	In % Full Scale Deflection	In % Instantaneous Reading
High range Full Scale = 10 t.p.h. liquid 1.38 S.G.	15.0	1.50	383	265.9	1.54	+ 0.04	+ 0.4	+ 2.7
	40.4	4.04	145	263.3	4.04	Nil	Nil	Nil
	60.0	6.00	97	263.6	6.03	+ 0.03	+ 0.3	+ 0.5
	79.5	7.95	73	265.2	8.05	+ 0.10	+ 1.0	+ 1.3
	99.0	9.90	59	265.8	10.00	+ 0.10	+ 1.0	+ 1.0
Low range Full Scale = 2.5 t.p.h. liquid 1.38 S.G.	25.5	0.637	953	265.7	0.617	- 0.02	- 0.8	- 3.1
	43.5	1.09	563	266.1	1.050	- 0.04	- 1.6	- 3.7
	56.5	1.41	428	265.6	1.38	- 0.03	- 1.2	- 2.1
	68.0	1.70	351	265.6	1.68	- 0.02	- 0.8	- 1.2
	99.3	2.48	240.5	265.6	2.45	- 0.03	- 1.2	- 1.2

TABLE V

Water Calibration of magnetic flowmeters, normal duty 1.84 sulphuric acid

	Flowmeter reading in t.p.d. 1.84 S.G. acid	Duration of test in secs.	Actual wt. of dock water (1.027 S.G) in lbs.	Equivalent in t.p.d. 1.84 S.G. acid	Error		
					In t.p.d. acid	In % Full Scale Deflection	In % Instantaneous Reading
X Side Meter	500	30	229.5	528.6	+ 28.6	+ 5.7	+ 5.7
	500	30	228.5	526.3	+ 26.3	+ 5.3	+ 5.3
	250	60	226.5	260.8	+ 10.8	+ 2.2	+ 4.3
	250	60	225.5	259.7	+ 9.7	+ 1.9	+ 3.9
Y Side Meter	500	60	437	503.2	+ 3.2	+ 0.6	+ 0.6
	500	60	436	502.1	+ 2.1	+ 0.4	+ 0.4
	500	60	435	501.0	+ 1.0	+ 0.2	+ 0.2
	250	60	217	249.9	- 0.1	nil	nil
	250	60	216	248.7	- 1.3	- 0.3	- 0.5
	250	60	217	249.9	- 0.1	nil	nil

C. COMMINUTED SOLIDS

About four years ago we decided to embark on a programme of measurement and control of solids flows throughout our Works in order to bring this aspect of process control into line with the existing complete instrumentation of fluid flows. The applications included the continuous indication, recording, totalling and/or controlling of solids flows, and interconnection in ratio with other solids and fluid flows.

We are aware that specialised equipment was commercially available for these various purposes, but there were disadvantages. For instance, solids flow indicators were expensive and generally not sufficiently robust to withstand the ardous conditions encountered in a fertilizer works. They soon became corroded and clogged, and consequently "sticky" and inaccurate in reading. Most controllers were not continuous in operation and therefore did not respond quickly enough to changes in feed, and they did not provide a record, or means for easy interconnection in ratio. Furthermore, specialised equipment was necessary for each different function.

We therefore carried out a survey of available equipment to try to find a solids flow measuring device with the following characteristics:-

1. Versatility: capable of providing flow indication (local and remote), recording, totalizing, and/or control, as required. Also, easily fitted into existing solids handling equipment, and not tailor-made for each application.
2. Simple, accurate, and robust.
3. Free from "stiction", hysteresis, and drift even when subjected to ardous working conditions.
4. Damped sufficiently to be unaffected by structural vibration and extraneous disturbances (e.g. caused

by the passage of belt-fasteners), and yet quick enough in response to follow significant fluctuations in flow, and capable of transmitting a signal accurately proportional to the mean flow.

5. Easily incorporated into proportioning and ratio-control schemes.

We failed to find any equipment possessing all the above characteristics, and therefore proceeded to develop our own solids flow transmitter to meet the requirements. We decided to concentrate our attention upon belt-weighing, because it is the most widely applicable and fundamental way of measuring solids flows continuously, and is least affected by variations in the material which is being weighed. This is true even when it would otherwise be convenient to use completely closed-duct solids conveying systems. Closed-duct weighers employ accelerative or impact principles, and are not generally suitable for fertilizer materials because of the variability of the physical properties of these materials. Also, they are highly specialised pieces of equipment and involve structural modifications and the provision of a head of material.

The belt-weight transmitter which we developed (and which is the subject of British and Foreign patents) is shown diagrammatically in one of its forms in Fig. II. Basically it is a weighing carriage fitted with a transmitting pneumatic load cell. It is designed to support any type of flat or troughed idler, and can be mounted on the stringers under all normal conveyor belt installations without modifications to the structure or the provision of a bridge over the belt.

Referring to Fig. II, idler C, and counterbalance weights D and E are mounted on a main beam which is cross-braced for rigidity and designed to present the smallest possible area for accumulation of dust. It is supported by steel crossed flexure strips at L. These locate the beam accurately and allow it to pivot without "stiction", even when covered with

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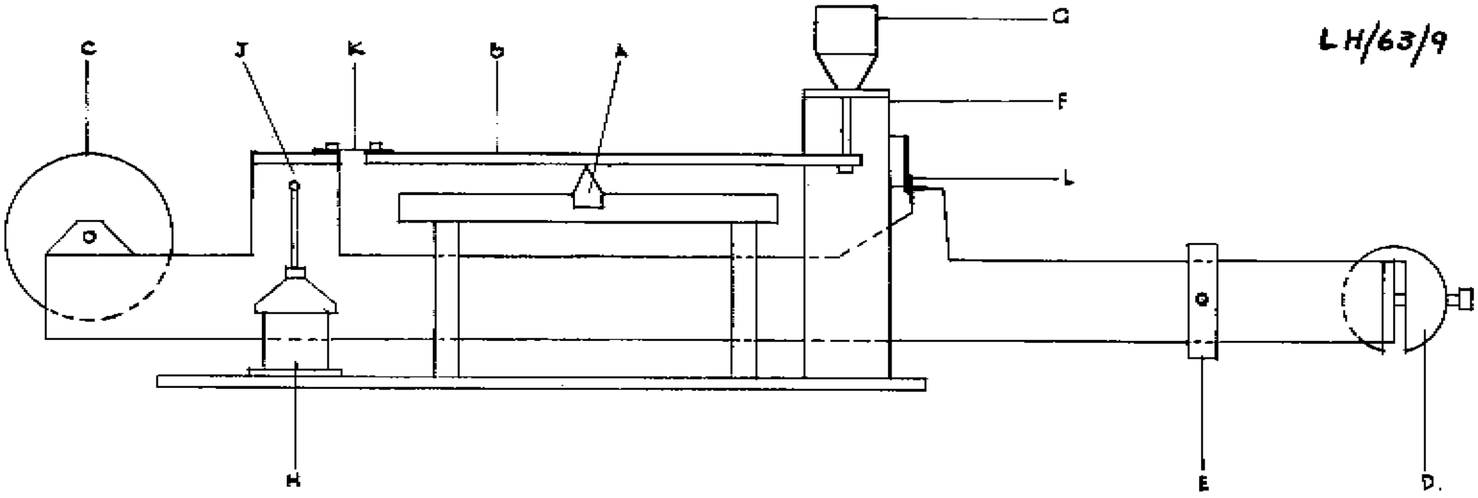

A = ADJUSTABLE FULCRUM.
B = SPRING LEVER TO TRANSMIT WEIGHT OF SOLIDS.
C = IDLER
D = DEAD WEIGHT TO BALANCE WEIGHT OF IDLER C AND EMPTY CONVEYOR
E = SLIDING WEIGHT FOR FINE ADJUSTMENT.
F = THRUST ROD
G = LOAD CELL
H = DASHPOT
J. = DASHPOT LEVER
K, L, = FLEXURE STRIPS.

FIG. II. - SOLIDS FLOW TRANSMITTER

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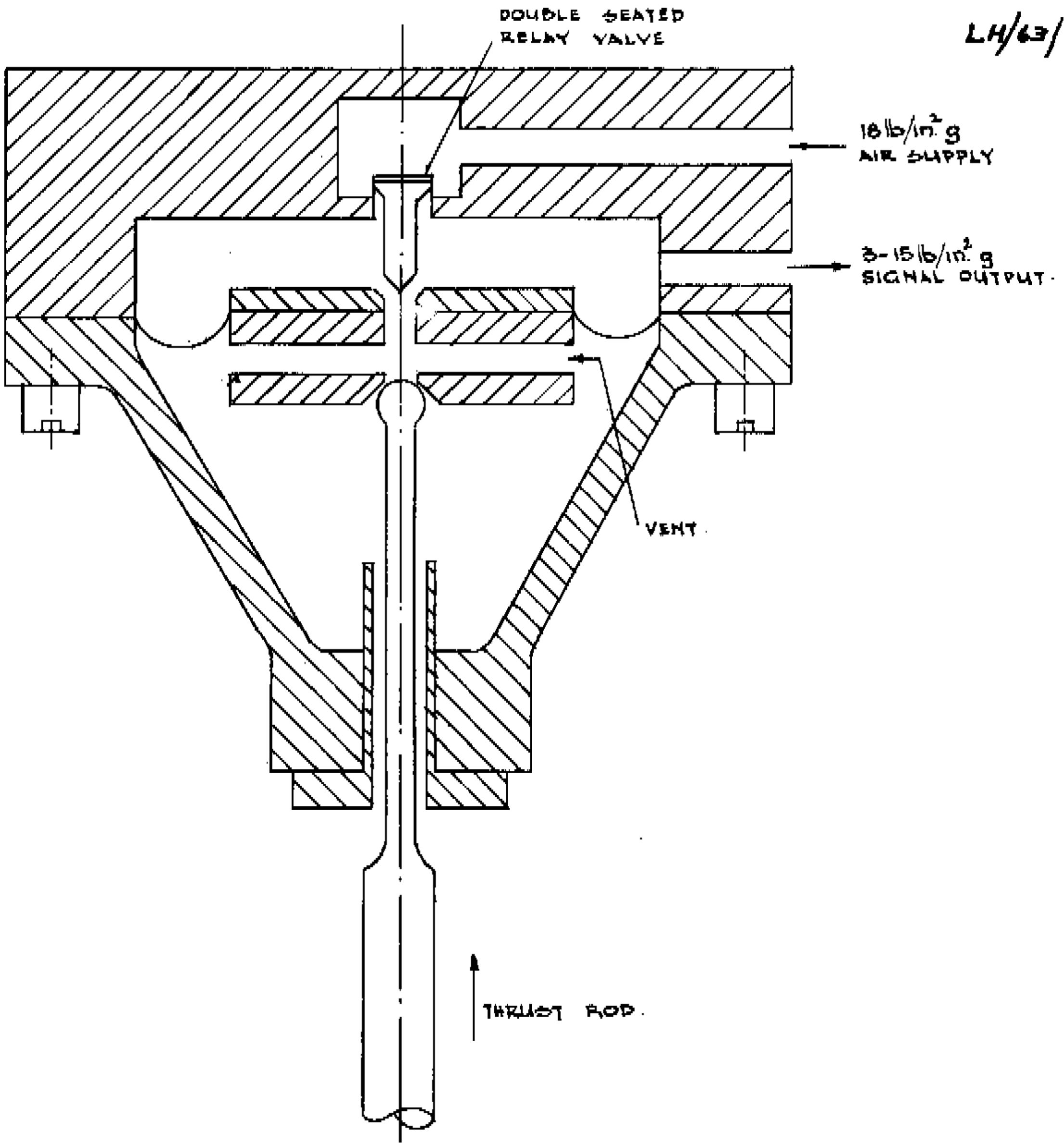

FIG. III. - LOAD CELL

corrosive dust. The weight of idler C and the empty conveyor belt is balanced by weights D and by other weights E, sliding on the side of the main beam for fine adjustment. The weight of the solids on the belt is transmitted by spring lever B and the adjustable fulcrum A to the thrust rod F of the load cell G.

The load cell is shown diagrammatically in Fig. III. It is a very simple pneumatic force-balance cell which acts as a direct transducer of load into the standard instrument air output signal of 3 to 15 psig. It can be seen that the thrust created by the weight of solids on the belt is directly supported by the air output pressure acting upon the diaphragm. Because true force-balance is used, the diaphragm does not move significantly (only about 0.001 inch). Therefore its effective area does not change and the output pressure bears an exactly linear relationship to load: also diaphragm hysteresis is eliminated. There is an air bleed in the small double seated relay valve, so that the effective area on which the air pressure acts is not altered by the valve resting on alternate seats when loads are increasing and decreasing. The vertical mounting of the cell, together with the small air leak, renders the device self-cleaning and impervious to dust.

It would be equally easy to mount a strain-gauge load cell on the weighing carriage, but it would not be as satisfactory. The strain gauge load cell has many well-known applications where it would be difficult, if not impossible, to use any other method, but this particular application is not one of them. It has to be remembered that the strain gauge is not a direct transducer of load into electrical signal. It is in fact, a rather crude form of spring balance to which is attached an inferential motion transmitter. Great care in design and construction is necessary to limit the errors inherent in such a system. There is no doubt that satisfactory results have been achieved, but the cost of the equipment must remain comparatively high. Another disadvantage is that, for acceptable accuracy, the receiving instruments are expensive, complex and fragile, as compared with pneumatic receivers. A closely-allied load cell is the stiff spring, carrying a sensitive differential transformer motion transmitter. The same remarks apply to this as to the strain gauge type.

The adjustable fulcrum A is provided so that the output of the load cell can be calibrated on site to give the standard instrument output signal of 3 to 15 psig for any weigh-belt span or loading and to obtain a suitable whole-number full scale reading (e.g. 25 tons per hour) on the associated indicators and recorders, depending upon the measured belt speed. This is of the greatest importance in achieving versatility of application, and to ensure that the weight transmitter can be used with standard instruments for indicating, recording, totalling and controlling, and in ratio systems.

The lever, B, is in the form of a stiff spring in order to allow just sufficient movement at the dashpot, H for effective damping. As previously mentioned, the movement at the load cell is inappreciable, and therefore damping at this point would introduce practical difficulties. Input damping is necessary because the rate of response of a force-balance pneumatic load cell is not symmetrical for rapidly-increasing and rapidly-decreasing loads. Consequently, output damping would not give a true mean of the input unless the rate of change of input had previously been slowed to be within the response speed of the load cell. Very rapid fluctuations in load occur in practice mainly because of vibration of the plant structure itself, the passage of the belt fastener, and lumps of material adhering to the weigh idler and underside of the belt. These disturbances are clearly unwanted and should be removed as far as possible.

The dashpot piston is provided with adjustable apertures so that the degree of damping can be altered to remove extraneous disturbances and to reduce noise sufficiently to provide a significant output record. The output remains an accurate measure of the mean mass flow of solids because the relationship between the two is linear, and no root mean square error is introduced by damping.

An outstanding feature of the arrangement of the spring-lever and the fulcrum is that the deflection of the weigh-idler and the degree of damping (once adjusted) remain constant even when the position of the fulcrum is adjusted to give the standard transmitter output for different applications and belt loads. It is most necessary to maintain the deflection of the weigh idler at a small and constant value in order to avoid weigh-belt errors; this is done automatically by the spring-lever and fulcrum, for all load ranges.

For locations where space is restricted there is another form of the weigher in which the counterbalance half of the main beam is removed and replaced by a zero spring which balances the weight of the idler and empty belt. For belts over 30" wide, load cells are used on both sides of the machine and their outputs are summed. For belts up to 30" wide, a single load cell, spring beam, and dashpot, are mounted on one side, the main beam being well braced to withstand the torsion caused by this one-sided support.

It should be noted that, when truly continuous methods of load measurement, integration, and control are used, there is no advantage in using a multi-idler belt weighing machine, except where very heavy fast-running conveyor belts are used, with closely-spaced idlers. The single-idler weigher has obvious advantages in simplicity and ease of installation and is suitable for most applications in a fertilizer works except perhaps for heavy intake conveyors.

Accuracy of Solids Flow Measurements

There are four factors to be considered when assessing the accuracy of a solids flow measuring installation:-

(a) Accuracy of the belt weight transmitter itself, purely as an apparatus for measuring and transmitting the load applied to the weigh-idler.

(b) Accuracy of the associated instruments e.g. recorders and integrators.

(c) Accuracy of the conveyor or weigh-belt, and belt-drive installation, as a means of applying the weight of solids per unit time to the weight transmitter.

(d) Accuracy of control, where applicable.

Dealing with each of these in turn:-

(a) Accuracy of the New Belt Weight Transmitter

Tests using deadweights were carried out by mounting the machine horizontally and suspending certified weights from a strap hanging freely from the centre of the idler. The output signal was measured on a 40 in. mercury manometer.

The machine was tested at various settings of the span adjustment to give full-scale output-readings for applied weights of 12 lb, 24 lb and 48 lb. In all cases the calibration was arranged (by adjusting the position of the fulcrum) so that the air output was as near as possible to 6 in. mercury gauge at no load and to 30 in. mercury gauge at full load. In practice, of course, it would be adjusted to give a signal between 3 $\mathrm{lb/in}^2$ and 15 $\mathrm{lb/in}^2$.

The tests were carried out with the weights being gradually applied, and then with the weights being gradually removed. This was done to check whether there was any hysteresis effect and to see if the results were repeatable. Since there was no difference at all, only a single reading is given for each weight.

To check for drift, a load was applied for a period of 48 hours and no difference in output could be detected over this time.

The 40 in. manometer (which was, of course, far more sensitive than any indicating instrument which would be used in practice) was read as accurately as possible by eye. Therefore, although the results are expressed to the second place of decimals, the readings themselves are subject to an error of about ∓ 0.01 - ∓ 0.02 in.Hg.

The results of the tests are given below:-

Calibration with Test Weights
(Ambient Temperature 63-65°F)

Span 1		Span 2		Span 3		"Ideal" output pressure for 100% linearity (in. Hg)
Load (lb)	Output pressure (in. Hg)	Load (lb)	Output pressure (in.Hg)	Load (lb)	Output pressure (in.Hg)	
0	5.98	0	5.95	0	6.00	6.00
2	9.95	4	9.95	8	10.00	10.00
4	14.00	8	13.95	16	14.00	14.00
6	18.01	12	17.95	24	18.00	18.00
8	22.05	16	21.95	32	22.02	22.00
10	26.05	20	25.95	40	26.03	26.00
12	30.05	24	29.98	48	30.00	30.00

To summarise these results, it can be seen that the maximum deviation of the signal from true linearity at any load on any span was 0.05 in. mercury gauge. For a full-scale span reading of 24 in. Hg this is just 0.2%.

It is therefore claimed that the accuracy and linearity of the machine itself, as a transmitter of weight applied to the weigh idler, is within ∓ 0.2% of full-span reading. Furthermore, repeatability errors, and errors due to hysteresis, stiction, and drift, are not detectable, i.e. they are less than 0.02 in. Hg or less than 0.08% of full span reading.

(b) Accuracy of the Associated Instruments

Reputable makers of standard pneumatic indicators, recorders, integrators and controllers, calibrate and test their standard instruments to limits of ∓ 0.5% of full scale reading. For greater accuracy, for instance in indication or during calibration, test-quality gauges or mercury manometers may be used.

(c) Accuracy of the Belt Installation

Incorrect installation can lead to gross errors (e.g. ∓ 50% or more) in applying the mass flowrate of solids to the idler of the weight transmitter. So many factors are involved that systemmatic treatment of the subject would require a separate paper, therefore only a few of the outstanding points will be mentioned.

The most important of these is the necessity for accurate alignment of the weigh-idler with the fixed idlers on either side. Any deflection of the weigh-idler with load must be small and reproduceable. The importance of alignment increases with stiffness, troughing, and tension of the belt, and with shorter spans between idlers. It should be noted that variable build-up of material on the idlers directly affects alignment.

Another cause of inaccuracy is adherence of material to the belt or absorbtion of moisture by the belt, thus increasing its weight. It is, of course, possible to compensate by weighing the return loop of the belt and deducting this from the forward weight. However, this practically doubles the weighing equipment or introduces undesirable extra linkages and idlers, and it is therefore preferable to use belts which are not subject to water absorbtion and which are easy to clean by suitable brushes and scrapers.

Finally (in this incomplete list) there is the question of belt speed. If this is not reasonably constant, it must be taken into account by incorporating an appropriate tacho signal. We have found this to be unnecessary in most of our applications because our weigh-belt and conveyor-belt driving motors are relatively lightly loaded and the drop in speed from conveyor-empty to conveyor-full is usually less than 1%. Therefore, if the weight transmitter is calibrated for the mean speed, the maximum error will not exceed ∓ 0.5%. We seldom experience slip in the belt drive.

It can be seen that the accuracy depends upon many factors; not least upon the material being weighed. If this is easy to brush or scrape off the belt and if it does not cause build-up on the idlers, then a well-designed installation should provide an accuracy within ∓ 0.5% F.S.D. With materials which adhere strongly and cause excessive build-up, it is not usually possible to improve upon ∓ 1.0% F.S.D.

(d) Accuracy of Control

The most important factor in the control of solids flows is the provision of a smooth, easily regulated, flow of material onto the weigh belt. Materials used in the fertilizer industry vary very widely in their flowing characteristics, therefore feed arrangements which would be suitable for one material may be quite unsuitable for another. The best guide is previous experience in handling the particular material. It is one of the chief advantages of the new transmitter that its versatility enables it to be incorporated into any feed system known by previous experience to be satisfactory.

For instance, ground phosphate rock is a difficult material to handle in that it fluidises easily and flows through small apertures like liquid; alternatively it can pack and choke in hoppers. Thus it is not easy to prevent starving and flooding of the weigh-belt. Figures 1V and V represent two different ways of handling this problem.

They are charts taken from undamped recorders.

Figure lV records the flow of ground phosphate rock to a Moritz den. There is a small feed hopper (holding about 1 ton) for the weigher. This is kept constantly full and overflowing by a screw conveyor, the surplus being returned to bulk storage. From the bottom of the small hopper we have another screw conveyor inclined upwards and delivering onto the weigh-belt. This screw is driven through a Carter infinitely variable gear-box with pneumatic positionerwhich is operated via a standard controller connected to the weight transmitter on the weigh-belt.

Figure V records the flow of phosphate rock to a wet-process phosphoric acid plant. In this case the rock is extracted directly from the bottom of a 50 ton hopper by means of a screw conveyor which feeds onto the weigh-belt. The screw is driven by a variable-speed electric motor regulated by a pneumatic power cylinder which is operated by a standard controller connected to the weight transmitter on the weigh-belt.

It can be seen that the control band-width (rapid fluctuation in feed) is less than ∓ 1% F.S.D. in the case of Figure lV and about ∓ 2% in the case of Figure V. The improved control in the case of Figure lV is due mainly to the smooth feed from the small hopper but also (to some extent) to the fact that the Carter gear responds more quickly to control signals than the electric motor with its greater inertia. It must also be pointed out that the large hopper installation (Fig.V) requires greater care in operation to prevent starving and flooding. It should be noted that the mean value of feed is well controlled in both cases, and the machines can be calibrated to deliver within ∓ 0.5% F.S.D. when tested over 5 minutes in the case of Figure lV and 15 minutes in the case of Figure V.

Raw materials for compound fertilizers do not flood, but they cause trouble due to their tendency to stick and choke in the hoppers, and to form lumps. Our standard extractor for such

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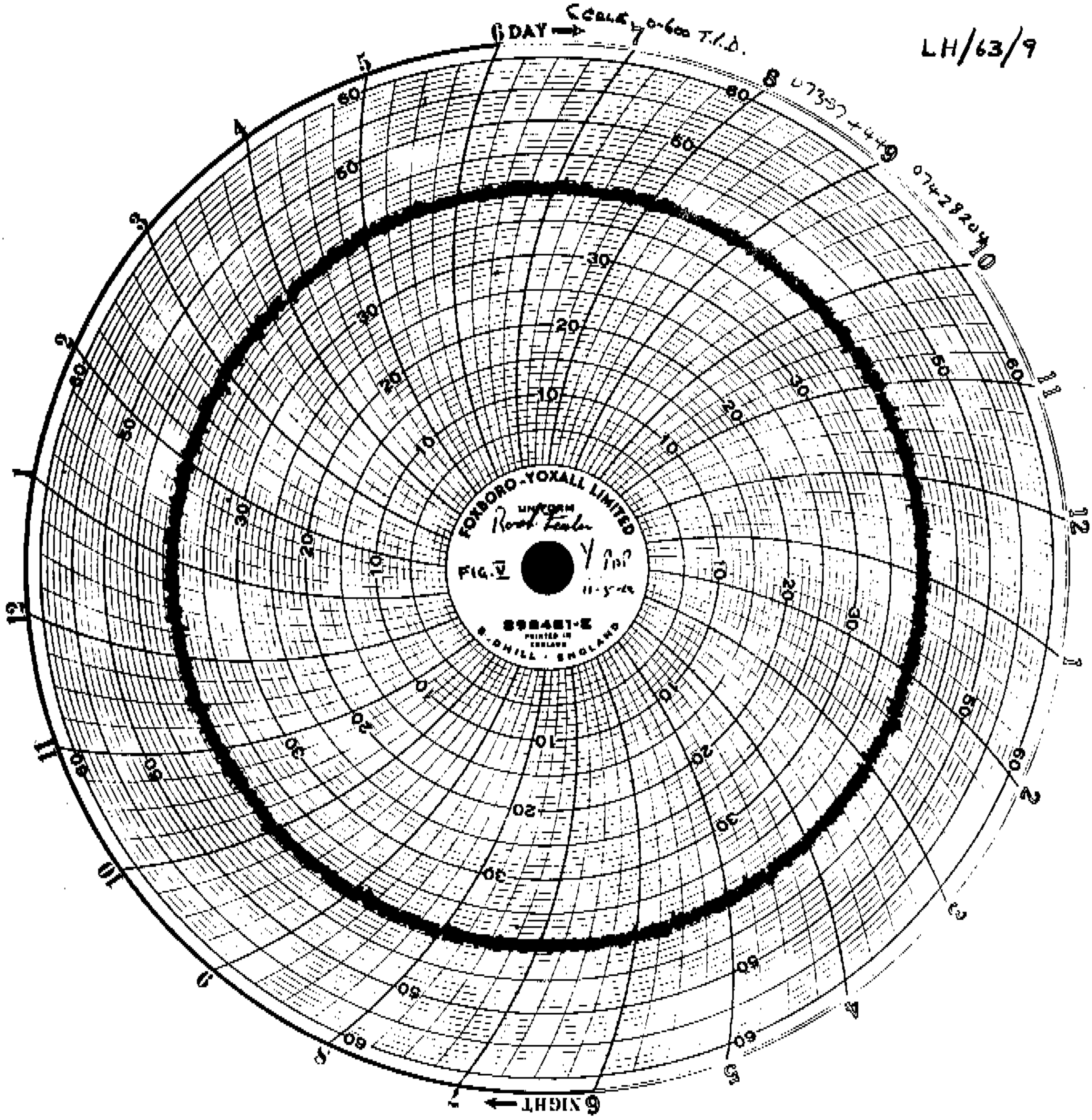
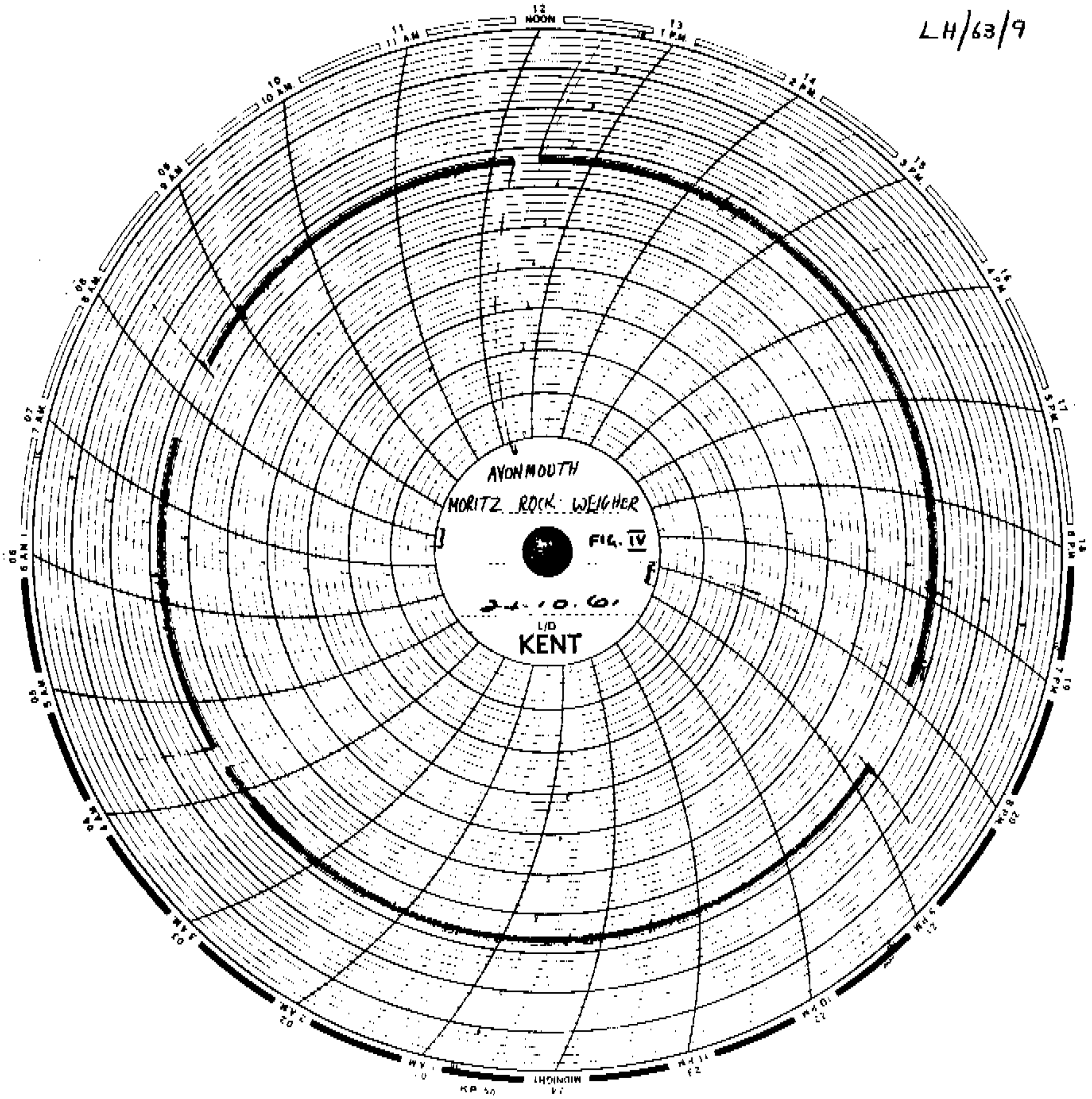


Scale 0-600 T/D.
073-37-449
074-28204
6 DAY
6 NIGHT
FOXBORO-YOXALL LIMITED
UNIFORM
Robert Fowler
11-5-
PRINTED IN ENGLAND
REDHILL · ENGLAND

FIG. V

LH/63/9



AVONMOUTH

MORITZ ROCK WEIGHER

FIG. IV

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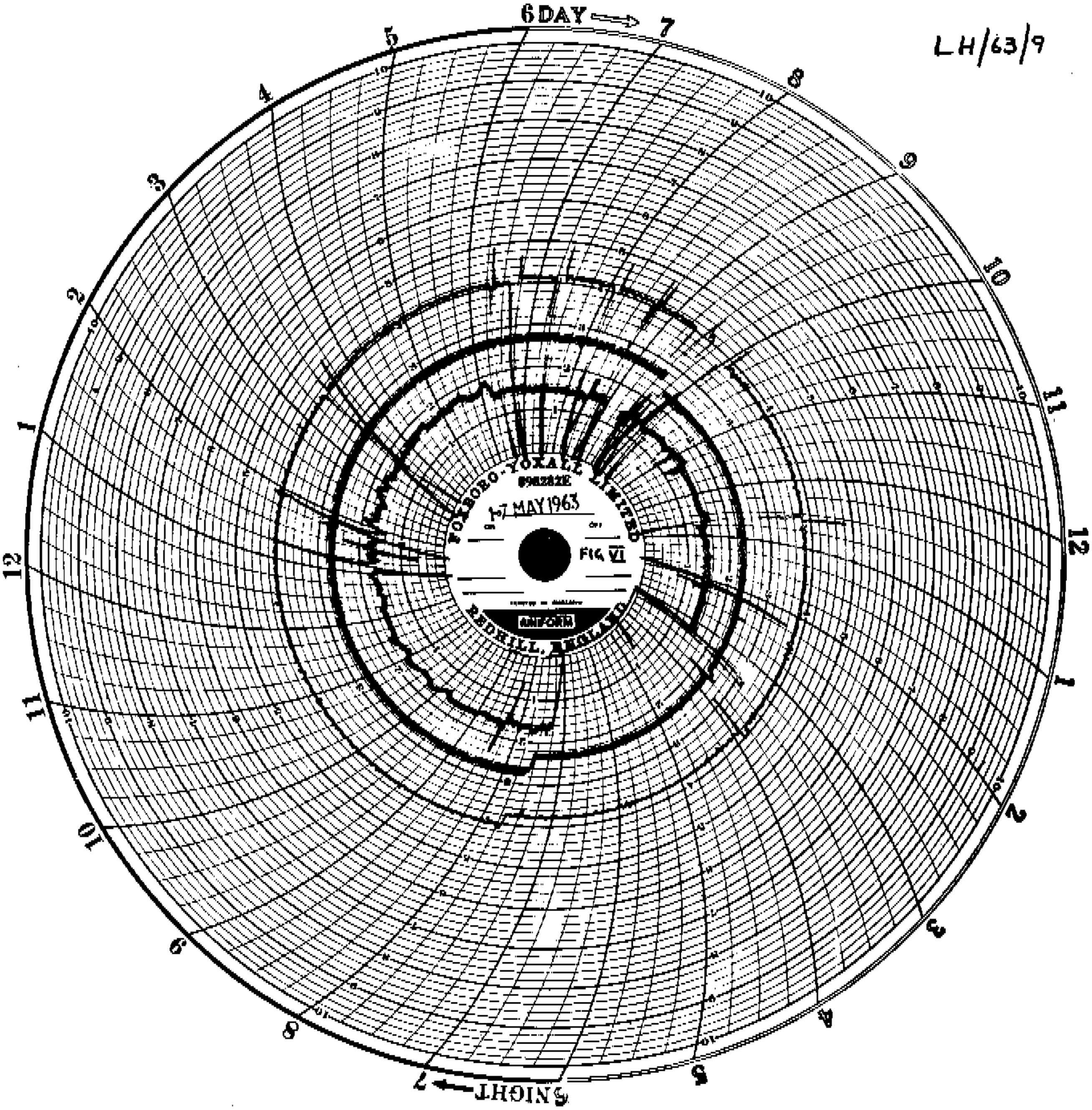
6 DAY
7
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NIGHT
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FOXBORO-YOXALL LIMITED
REDHILL, ENGLAND
1-7 MAY 1963
ON
OFF
ANFORM

FIG VI

materials is a heavy conveyor belt running right across the bottom of the hopper between the vertical back and front sides of the hopper. This conveyor is too stiff and tight for accurate weighing, so we arrange for it to discharge onto a separate weigh-belt incorporating the weight transmitter which regulates the speed of the extractor belt. The resulting control is quite good, as can be seen from Fig. VI which shows the records obtained from 3 raw materials weighers. However, severe choking of the feed from the hoppers can be seen in the case of two of the raw materials.

Granular fertilisers are, in general, convenient to handle. They flow freely but do not flood. It is quite easy to feed such materials directly onto a weigh belt in a simple, accurate, installation, with optimum control characteristics.

To sum up the remarks on control, the frequency and amplitude of control disturbances depend mainly on the material which is being handled and the efficiency of the hopper, extractor, and feed arrangements. But it should always be possible to achieve an accurate mean value, providing that completely uncontrollable choking and flooding are avoided. Therefore, in respect of mean value, the control itself should introduce no additional errors. The quality of control does, however, affect the accuracy over short periods of time. For instance, if the instantaneous accuracy is considered (i.e. if the machine could be tested over an infinitesimal period), then the control-width shown on Fig. V would introduce an additional error of ± 2%, and less than ± 1% for Fig. IV. This short-term inaccuracy is sometimes of little practical importance.

With a continuous weight transmitter and continuous control system, the accuracy remains unimpaired however short the test period, in cases where the characteristics of the comminuted solid enable it to be fed perfectly smoothly onto the weigh belt. This, of course, cannot be achieved by weigh-feeders employing discontinuous methods of control.

Tests on some installations measuring and controlling solid flows

1. A bulk test was carried out simultaneously on two installations handling granular materials, and each comprising a 10 ton hopper fitted with a fixed-speed extractor belt and discharging onto a fixed-speed weigh belt incorporating the new weight transmitter. The signal from the weight transmitter is taken to a standard recorder-controller which then regulates the gate opening on the extractor.

The flow rates of the two recorder controllers were set to a combined total of 28.33 tons per hour. During a run of 30 hrs. 3 mins. the bulk delivery from the two machines totalled 850 tons, which is equivalent to 28.26 tons per hour. Thus the combined error of the two installations was - 0.07 tons per hour, or 0.2% of actual scale reading. It should be noted that the weighers had been calibrated by certified test weights, calculated according to the weigh length and measured belt speed. They had not been previously calibrated by weighment of material actually delivered.

2. Short-period tests were carried out on an installation comprising a 5 ton hopper from the bottom of which granular material is extracted directly by an 18" flat weigh-belt running at 7.97 ft. per minute and incorporating the new weight transmitter. The signal from the latter is taken to a test-quality pressure gauge as a flow-indicator, scaled 0 at 3 psig and 100 at 15 psig. The same signal is fed to a controller and thence to a power cylinder operating a gate to regulate the amount of material extracted from the hopper. The weigher was calibrated by test weights, as for 1. above, and the calculated rates of delivery given in the table below were obtained by simple proportion from this dead-weight calibration.

The granular material was collected in tared bags and weighed on a calibrated platform scale. Operation of the flap-valve to divert material into the bags, and timing, was carried out manually. The controller was adjusted to three different settings and ten consecutive weighments were collected at each setting for two different collection periods. Every weighment, without omission, is included in the results tabulated below:-

Period of collection in minutes	1.0	0.5	2.0	0.5	5.0	0.5
Gauge reading in % of full scale. (i.e. weigher output)	91.0	91.0	51.0	51.0	21.5	21.5
Rate of material delivery in lbs/min as obtained from each weighed bag in sequence	65.6 64.5 65.5 65.5 65.25	65.5 65.0 64.25 64.5 65.75	37.4 37.25 37.25 37.25 37.4	36.75 37.0 37.0 37.0 37.0	15.75 15.8 15.9 15.8 15.8	15.1 15.9 15.9 16.1 15.8
Mean Rate in lbs/min	65.3	65.0	37.3	37.0	15.8	15.75
Calculated Rate from dead weight calibration	65.5	65.5	36.7	36.7	15.5	15.5
Maximum deviation from mean in % full scale	1.1	1.04	0.14	0.35	0.14	0.90
Deviation of measured mean from calculated mean in % full scale	0.3	0.7	0.6	0.4	0.4	0.3

3. Finally, there are some tests on an installation comprising five weighers controlling the flow of raw materials for compound fertilizer manufacture, and one machine for returned fines. Each of these consists of a 10-ton hopper equipped with a belt extractor driven by a motor through a Carter infinitely-variable gear box. The extractor discharges onto a weigh-belt driven by a separate motor through a manually-selected 2-speed gearbox. The weight transmitter on the weigh

belt sends a signal to a recorder-controller, and thence to a pneumatic positioner on the Carter gear box to regulate the speed of the extractor belt. The 2-speed gear boxes are fitted to increase the flow range of accurate control to 20:1.

These particular machines are calibrated by tared chains laid on the weigh belt. Periodically, all the machines are tested by collecting and weighing the material delivered during periods of from 5 minutes at the higher rates, to 15 minutes at the lower rates.

The weigh belts are run at low speed for testing at 1 and 3 tons per hour, and at high speed for rates of 10 and 15 tons per hour. The results of one complete series of tests are given in the table below. For a particular reason, these machines are not calibrated to a whole-number of tons per hour at full scale reading. The full scale deliveries for all the machines except A3 are approximately 3.2 tons per hour at low belt speed and 17.9 tons per hour at high belt speed. Machine A3 controls returned fines and has a full scale delivery of 31.4 tons per hour at fast speed only.

Machine No.	Set Rate in tons per hour	Error in % Set Rate; i.e. % Instantaneous Reading	Remarks
A1	1	+ 0.63	Av, 2 tests
"	3	+ 0.40	Av. 3 tests
"	10	+ 0.83	"
A2	1	+ 0.12	"
"	3	+ 0.42	"
"	10	+ 0.50	"
A3	10	- 0.36	1 test only
"	15	+ 0.71	"
B1	1	+ 0.42	Av.3 tests
"	3	+ 0.16	"
"	10	- 0.39	"
B2	1	+ 0.72	"
"	3	+ 0.75	"
"	10	+ 0.75	"
B3	1	- 0.37	"
"	3	+ 0.72	"
"	10	+ 0.47	"

Acknowledgements

The author wishes to thank colleagues at the Immingham, Cliff Quay, and Avonmouth Works, and at the Bramford Development Station of Fisons Fertilizers Limited, for the test data presented in this paper. Messrs. L.A. Mitchell Ltd., have kindly allowed the author to publish the details of the solids weight transmitter, for which they are the patent lincencees.

The permission of the Directors of Fisons Fertilizers Ltd., to publish the paper is gratefully acknowledged.

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   H.M. Stationery Office 1962.

DISCUSSION:

Mr. J.C. FARQUHAR (United Kingdom) : This is a specialist paper to a general audience, but I have not on that account over-simplified it in any way. I have included the fullest practical information in our possession, within the limits of the length of the paper. However, although a specialist paper, I believe it will be of general interest to everyone, for, if the ingredients cannot be metered and controlled properly, the product quality cannot be guaranteed.

I have emphasised the importance of calibrating meters. If they are not calibrated, considerable errors can result. From this point of view, Table 3 is interesting. We calibrated a variable area type meter and a magnetic flow meter on water. Then we passed the same process stream of hot ammonium nitrate solution through both meters, and there were considerable differences between them. We have no method of calibrating a meter on hot ammonium nitrate solution; and so we simply assumed that the magnetic flow meter was correct, and this has been confirmed by stocks and analysis. But the differences of up to 8% between the two types of meter suggest that, if it were possible, it would be better to calibrate a meter on the actual process fluid under the conditions obtaining during plant operation.

Another interesting point emerges from Table 5. The meter referred to as "X side meter" was over 5% in error when received from the manufacturers. This can happen to anybody at any time, unless these meters are checked.

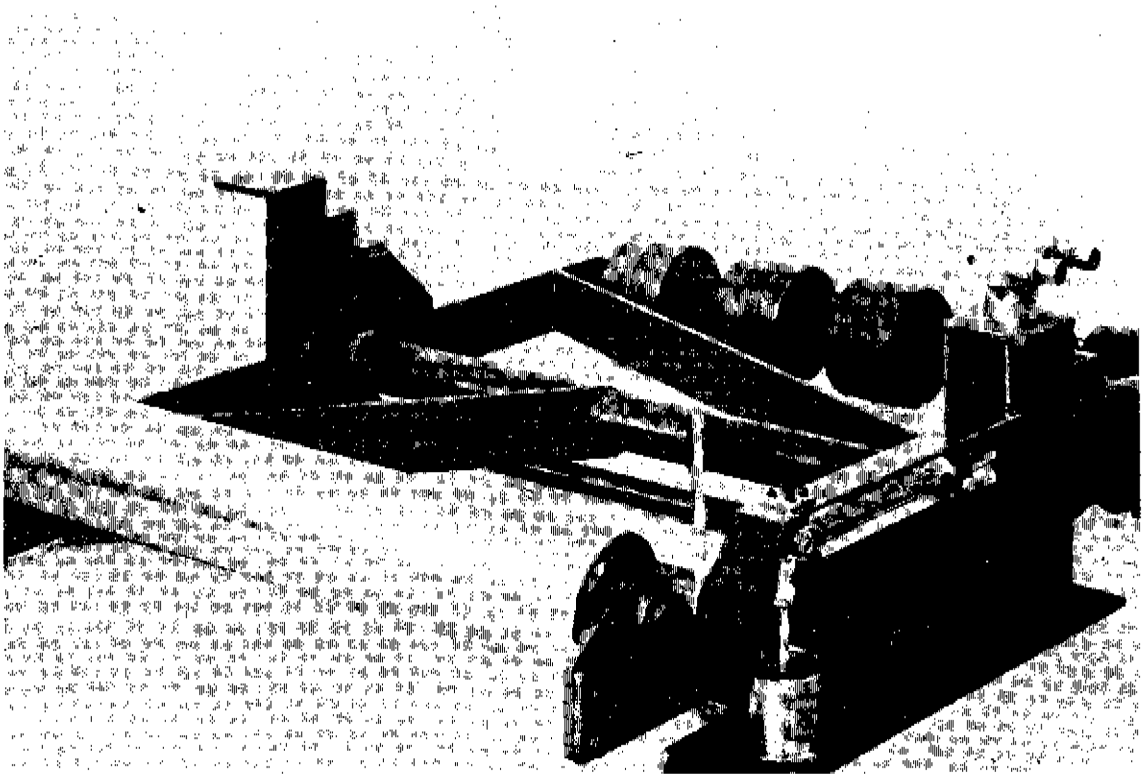
A point which I omitted from the paper concerns those few occasions when one has a large surplus pressure from a gas and one wishes to measure its flow. One can use the supercritical flow method, which is both accurate and cheap. For example, suppose one had a 300 p.s.i.a. steam supply to feed to a granulator, one can insert a flow nozzle. The back pressure on the granulator pipe would not exceed 5 p.s.i.g., making 20 p.s.i.a. One can thus decrease the flow-nozzle inlet pressure from 300 p.s.i.a. to 40 p.s.i.a. and still maintain flow through the nozzle at the velocity of sound. One then obtains a very accurate linear flow measurement merely by means of a single pressure gauge, over a flow-range, in this case, of $7\frac{1}{2}$ to 1.

Another omission concerns anhydrous liquid ammonia measurement, and I shall try now to summarise our findings on this subject. We meter a supply of anhydrous liquid ammonia at about 300 p.s.i. and 5°C at about 60 gallons per minute. We obtain a totalled meter reading for purchasing purposes, and it must thus be highly accurate. We tried a number of meters which failed completely owing to inaccuracy or, in the case of positive displacement meters, owing to wear caused by the very poor lubricating quality of liquid ammonia. Then, with considerable doubts, we tried a turbine meter - the De Havilland Potter meter. De Havilland tried various impellers and bearings to obtain the best results. The first such meters failed, because the rotor speed was too high and the bearings failed. Eventually they provided a meter with glass-impregnated Teflon bearings running at medium speed, and this meter was checked daily against a 30 ton weigh tank, both by our suppliers and by ourselves. Over a period of 2½ months, using the initial De Havilland water calibration, we obtained a total difference of 0.09% between the weigh tank figures and those of the meter. This was really remarkably good for any form of meter. We have used these meters continually since then for the purchase of ammonia, the value of which amounts to several million pounds per annum. The supplier has one such meter and we have another, and we have agreed that, if they differ, the weigh tank is to be used to decide which is right. So far they have never differed by more than 0.1% .

Mr. FARQUHAR then showed a number of photographic slides, including those shown opposite, as follows:

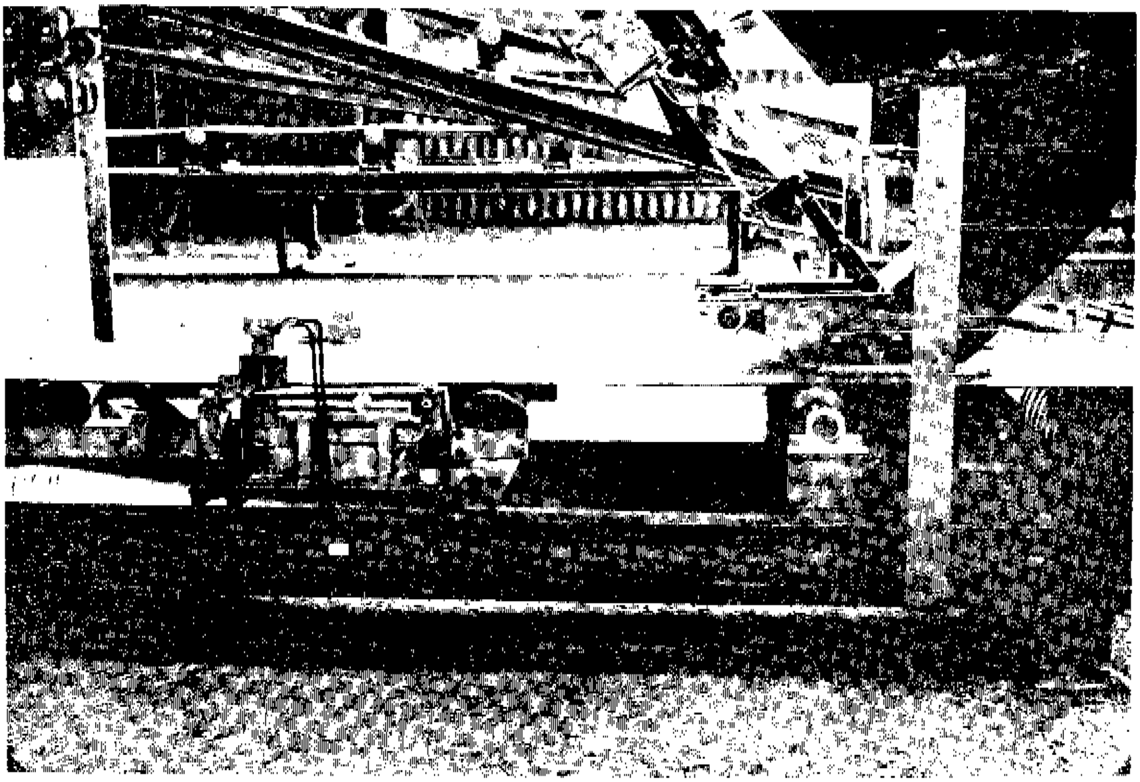
1. A solids flow transmitter with dead weights on the back to balance the weight of the belt and idler. The dashpot can be seen in the centre foreground and the load cell on the right.

2. The weight transmitter mounted as a constant weight feeder, handling granular materials, which slide down an inclined chute from a large hopper. The gate at the bottom is operated by a power cylinder and regulates the stream of granules flowing on to the weigh belt passing over the transmitter.



1. A solids flow transmitter, with dead weights on the back.

Un transmetteur de débit des solides avec tare au dos.



2. A weight transmitter mounted as a constant weight feeder.

Un transmetteur de poids monté comme alimenteur à poids constant.

Mr. N. LAGERHOLM (Sweden): Most, if not all of us, must have come into contact with the subject of Mr. Farquhar's paper at some time or other. Metering and control in our industry are important and present problems which never seem to be entirely solved. The complexity of the subject may be readily understood from, for example, Mr. Farquhar's analysis, in the first part of the paper, of what is meant by error and accuracy.

The disadvantages of differential pressure elements in general, and of orifice meters in particular, have been pointed out in an illustrative way. Mr. Farquhar's preference for variable area meters and magnetic flow meters for liquids seems to be in accord with our own experience. I seem to remember, however, that a few years ago, when the possibility of installing a magnetic flow meter was raised in my company, the capital cost turned out to be somewhat more discouraging than Mr. Farquhar suggests. It may be, however, that matters have changed since then.

Could Mr. Farquhar say whether the electric conductivity of the liquid to be measured by the magnetic flow meter has any appreciable effect on the results ?

I should also like to ask Mr. Farquhar if he could elaborate somewhat on the influence of viscosity on variable area flow meters.

In the case of comminuted solids, Mr. Farquhar has described a very interesting transmitter developed by his company. It seems to be working very well, but I am not quite sure if I have completely understood the functioning of the pneumatic load cell. Could Mr. Farquhar clarify this ?

My company has had some experience with a strain gauge load cell, and I agree that it has a number of serious disadvantages.

Could Mr. Farquhar say whether his pneumatic load cell, or his flow transmitter as a whole, is on the market for sale ?

Mr. FARQUHAR: With regard to the capital cost of installing a magnetic flow meter, Mr. Lagerholm is quite correct. I have included the entire installation - the transmitter, the receiver-recorder-controller, and the control valve - in my estimate that the magnetic meter costs about twice as much as the variable area meter; but if you merely compared the meters themselves, the difference would be considerable. Very roughly, I think the variable area installation of about the size used by Fisons costs about £350 and the whole magnetic installation costs about £700.

With regard to the electrical conductivity of the liquid to be measured by a magnetic flow meter, this has no effect on accuracy at all, provided that it is over a certain minimum which varies with the make of meter. Certain manufacturers are putting low conductivity meters on the market; but, since we in the fertiliser industry are not concerned with oils and pure solvents and similar materials, it can be said that, in general, anything with a conductivity equal to tap water or more is measured accurately by the magnetic meter.

Concerning the influence of viscosity on variable area flow meters, this is a very specialised subject, and all I can say is that certain manufacturers make floats which they call "viscosity insensitive". However, they are only comparatively insensitive to viscosity. The viscous drag of the liquid flowing past the float tends, in fact, to raise it to a higher position than that at which it ought to be, and thus the reading of the meter will be high and its delivery low. Here again, the magnetic meter is advantageous, because it is completely insensitive to viscosity.

I can best answer Mr. Lagerholm's query concerning the functioning of the pneumatic load cell by referring to Figure 3 facing page 33 in the paper. The small valve marked "double seated relay valve" is merely a very small pin valve with two seats, one at the head and one at the lower point. If the load on the thrust rod exceeds the air pressure multiplied by the area of the diaphragm, the diaphragm will rise, lifting the top head of the small valve off its seat and admitting air from supply, until the chamber above the diaphragm exerts an equal pressure to that from the thrust rod. If the pressure on the thrust rod is less than that on the diaphragm, the whole diaphragm assembly will move downwards, until the lower point of the relay valve is free of the seat (as shown in the drawing). Air is then vented out of the chamber, until the diaphragm re-seats itself on that valve. There is, however, a small, constant leak to prevent the valve from seating on one seat and then the other, thus altering the effective area.

With regard to the general availability of the transmitter, Fisons have, in fact, sold the licence to L.A. Mitchell & Co., of Manchester, and they are handling it independently. Application should thus be addressed to them.

Mr. R. ARDOUIN (France) : I should like to put the following four questions :-

a) Referring to page 16 - "advantages-(b)", is the same magnetic flow meter as accurate for rates of flow varying, for example, from 800 litres to 8,000 litres per hour? Is this range not too large?

b) Are there any such flow meters in service in the industry for hot concentrated solutions of ammonium nitrate; for example, concentrations of between 85 and 92% at a temperature of about 120°C ?

c) In a granulation plant, where do you place the flow meter in relation to the slurry circulation pump?

d) Have you ever experienced icing inside a turbine flow meter for liquid ammonia? If so, what was the effect on its accuracy?

Mr. FARQUHAR : As to the first question, concerning whether a single meter could cover a flow range from 800 to 8000 l. per hour, this is a ten to one range, and the scale error increases by ten times at a tenth of the range. To cover that range with maximum accuracy, I should think one would need a twin-range switch on the meter, to switch on to high range for, say 4000 - 8000 l./hour, and on to low range for 800 - 4000 l/hr., the two ranges being chosen for convenience in reading scales and charts.

Regarding the question as to whether such meters are available to deal with hot, concentrated solutions of ammonium nitrate, this is the exact purpose of the magnetic meters and the variable area meters compared in Table 3, although our temperature is only 115°C i.e. slightly lower than that mentioned by Mr. Ardouin. This temperature does affect the lining material : even hard rubber becomes overheated at 120°C, and one should really use Teflon lining.

With regard to the position of the meter in a granulating plant, one should place it at the head of the ring main. There will naturally be a ring main from the tank farm up to near the granulator and back to the tank farm, and there will be a branch from the ring main leading to the granulator. We would include that branch in the ring main by fitting a three-way valve, automatically operated, so that, when the granulator is shut down, the solution can still flow through the meter and control valve, through the three-way valve, and back to the ring main and tank farm, at the same time automatically cutting the integrator out of circuit. When one wishes to use the solution, the three-way valve is changed over, and the meter and control valve are then steadily running, and the integrator is connected into the circuit.

We do not suffer from icing in our liquid ammonia flow meter, because our temperature is about 5°C; but I do not think this phenomenon should affect the meter at all, because there is nothing exterior to the meter except the pick-up coil. The whole meter assembly could be lagged quite satisfactorily to avoid deposits of ice, but such deposits should cause no trouble.

Mr. J.P.A. MACDONALD (United Kingdom) : Can Mr. Farquhar advise on a suitable form of continuous belt weigher for measuring the receipt of raw materials into a factory? To be acceptable, such a unit has to deal with a selected number of different raw materials. It has to measure at varying rates, resulting from such operations as ships' discharge, and, most important of all, it has to be sufficiently accurate to convince not only the purchaser but also the supplier.

Secondly, can the turbine type of meter be used for the metering of liquid ammonia to a process where a considerable variation in rate of flow was to be catered for?

Mr. FARQUHAR: Mr. Macdonald has raised an extremely difficult problem with his first question. Firstly it is essential that such a machine should have a Board of Trade Certificate. Our weigher was really made for the very many uses inside a works where such a certificate is not necessary for buying and selling. We have never even tried to obtain such a certificate. We have, and I feel sure Mr. Macdonald's company has also, a large number of continuous trade weighers of this sort, and we have varying results from them. I should not like to risk being unfair to any of these manufacturers; but, for example, we have one belt which becomes wet and absorbs well over 2% of the full scale range of the instrument in moisture. On a wet day this results in an error in excess of 2%. But personally, I have not been greatly concerned with these intake weighers : my main experience has been with the weighers internal to the plant.

As to the second question, we do use the turbine type liquid ammonia meter on processes, but I cannot give calibration data as I could for the other meters referred to, because we have no weigh tank in that circuit; but we presume they are as good as the meters we check daily, and, in fact, the total of the plant consumption does add up to the total liquid ammonia received. The flow range is not very considerable, because these particular process plants never run under half load, but we have no reason to doubt that an accurate range can be obtained over as much as ten to one, under optimum conditions.

Mr. N. D. GOPINATH (India) : The metering of liquids, gases and solids has been a problem in the fertiliser industry. As one who has been connected with these types of instruments for the last twenty years, I should like Mr. Farquhar to clarify certain points. Firstly, Mr. Farquhar states that differential pressure measuring elements should not be used with a D.P. cell. In fact,we are using differential pressure producing elements for metering even slurries, using a D.P. cell and flow meter with a controller and a receiver. The accuracy we obtain is about 0.5 to 1% in the case of a slurry.

My second point concerns the metering of liquid ammonia. Mr. Farquhar mentions the types of meters which can be used for this purpose. I presume the liquid ammonia is measured before the weigh tank; but I am not sure whether Mr. Farquhar means that he measures the ammonia from the tank cars. Anyhow, we use meters manufactured by Burgess Manning Moore, of America, of the variable area type and these have given us accurate results. The only trouble we have experienced concerns the installation. These meters, when installed after the let-down vessel, where the pressure is reduced to 300 p.s.i., will not give any trouble as Mr. Farquhar says; the dissolved gases in the ammonia do not affect it. If the installations were made correctly, the difficulties experienced in metering this liquid ammonia would probably be solved. Our experience with these variable area flow meters leads us to believe that the design could easily be altered: to put double the quantity of ammonia through the same meter, all that would be required would be an alteration of the float.

We have two installations for metering liquid ammonia, one with a measurement capacity of 60 tons/day, the other, 120 tons/day. The latter one was originally of the same capacity as the former one, but was converted to the additional capacity merely by changing the floats.

On page 13 of the paper, regarding the use of these variable area flow meters, Mr. Farquhar mentions the oscillations which occur due to flow variations in the gas. Usually, when ammonia gas is passed through the rotometer and with the ammonia being absorbed at the outlet, there are bound to be fluctuations in the float. This could be solved by the use of guided floats. In most ammonia installations, where the gaseous ammonia is absorbed in any vessel connected to the meter, the meter uses guided floats.

Finally, could Mr. Farquhar suggest a means of measuring a slurry containing roughly 40% of solids not volumetrically but by mass flow meter? We have examined the possibility of installing a magnetic flow meter combined with an electrodynamic corporation mass flow meter, but the cost is too prohibitive.

Mr. FARQUHAR: With regard to the point concerning the differential pressure cell, I did not say that it could not be used with a slurry. I merely said that we find it troublesome to use, because sealing vessels and purges are inclined to create difficulties; and we have found that the magnetic flow meter is a more reliable installation.

The second point related to Mr. Gopinath's experience in measuring liquid ammonia. Our own experience is completely the opposite. Moreover, we have done a great deal of very careful measurement on this subject and we are quite certain of our results. We have tried variable area and orifice meters and have checked them daily against a 30 ton weigh tank. The results from the variable area meter were no better than those quoted elsewhere in this paper, and even the manufacturers do not claim any better.

Concerning float bounce, the meters we use have guided floats - guided top and bottom - but they still bounce, so badly as to smash themselves to pieces. The system must be tuned off resonance in some way to eliminate this bouncing.

With regard to Mr. Gopinath's final question, I should not even try to attempt what he suggests, unless by using a magnetic flow meter and density meter by which mass flow was to be obtained regardless of expense.

Mr. A. FRELLUMSTAD (Norway): Mr. Farquhar strongly recommends a pneumatic load cell as a sensing element for his belt weigher. I presume that he also uses pneumatics all through the control loop. However, we have found at our plant that electronics may be advantageous in many cases. For instance, if you want to couple a magnetic flow meter with a belt weigher for ratio control, a conversion has to be made. I wonder if Mr. Farquhar could say at what point he would make this conversion to obtain best results.

Mr. FARQUHAR : Mr. Frellumstad has raised a very interesting and valuable point. The subject of electronics versus pneumatics has exercised everybody for many years, and I do not think we could start to discuss it here; but I think the pneumatic system still has a lot of life in it, particularly where force measurement is concerned, because the pneumatic force balance devices are very simple and reliable. It was for this reason that we used this type of load cell.

There is really no reason at all why pneumatics should not be converted into electonics, and *vice versa*, at any point desired. But with regard to Mr. Frellumstad's specific query about a magnetic flow meter coupled to a belt weigher, he is quite correct in assuming that we use pneumatics in the rest of our control loop. Our magnetic flow meter receiver is thus already fitted with a pneumatic controller and it is very easy to couple the two together in our case.

Mr. K.C. KNUDSEN (Denmark) : When using a belt weigher, one cause of inaccuracy is adherence of material to the belt and absorption of moisture by the belt. Mr. Farquhar states, on page 38, that it is therefore preferable to use belts which are not subject to water absorption and which are easy to clean by suitable brushes and scrapers. What material would Mr. Farquhar recommend for the manufacture of such belts ?

Mr. FARQUHAR : In our case, we have found that P.V.C.-covered belts of a particular formulation, which we obtain from B.T.R., generate a polished surface like glass, to which material does not adhere. However, I think this is a matter for experiment with the particular materials you use, because we have had some very variable results from certain other belts. Perhaps this P.V.C.-covered belt might not exactly suit your materials.

Mr. KNUDSEN : I think it would be alright : we would use it for superphosphate manufacture.

Mr. FARQUHAR : Yes, it would be alright for that.

Mr. ARDOUIN : I should like to revert to the magnetic flow meter. In paragraph (c) on page 14, you say that there is no need to fear mechanical breakdowns, and in para.(b) - "Disadvantages" on the same page, you say that it may require more complicated maintenance. Does this mean that other forms of breakdowns are possible, for example of an electrical nature? What does this maintenance consist of? You say "If it develops a fault...." Do you mean a fault in the current or in the electrical circuit?

Mr. FARQUHAR : Mechanical breakdown of the flow tube itself is very rare and is caused by damage to the lining or leakage at the electrodes, but after the preliminary work carried out by the manufacturers and ourselves, this has not occurred any more. Mr. Ardouin is quite correct in saying that what I was referring to as possible maintenance troubles would come in the electric circuitry. For example, we had a resistance failure inside the circuit of one such instrument, which put it completely out of action. This happened to be a new type of instrument with which we were not familiar, and so we had to call for the specialist engineer from the manufacturers to put it right. This he did in a fairly short time, but we could not have done it ourselves without a very well equipped workshop and special test equipment. If you had one such instrument in the middle of Africa, you would be in trouble, but if you had twelve such meters in the middle of Africa you would probably be alright, because you would have one or two complete spares. The possible number of electrical breakdowns are about as many as you would expect in your television set! They cannot be foreseen, and maintenance is nil, except for replacing the valves. Even then, we only replace the valve which fails and leave the rest until they, in turn, fail. However, I do not recommend this : valve changes in the amplifier could well be made a matter of routine.