

# THE USE OF STRAIN GAUGES IN THE MEASUREMENT OF PRESSURE FEEDER TORQUE AND INTERNAL CHUTE PRESSURE

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## Abstract

During the 1984 crushing season strain gauges have been used to measure mill torque, pressure feeder torque and internal chute pressure on diffuser bagasse dewatering mills at Amatikulu, Sezela and Maidstone. The methods and techniques employed to obtain torque and pressure are described in this paper. The relationship of these measurements to milling performance is discussed. The most important finding is that mill and pressure feeder torque are hardly affected by a change of speed and that only mill torque increases with an increase in hydraulic pressure.

## Introduction

With the increasing use of diffusers in the South African sugar industry and the problems experienced in achieving satisfactory bagasse moistures, it was found that some investigation into the performance of bagasse dewatering mills was needed. Very little is known about optimum mill settings, mill speed, hydraulic pressure and other parameters involved. In this light mill and pressure feeder torque measurements were carried out on dewatering mills at Amatikulu (AK), Sezela (SZ) and Maidstone (MS) and internal pressure was measured on the pressure feeder chute at MS.

There are various ways of measuring torque and pressure. The most obvious and perhaps most common method is using strain gauges. This method which is based on the change of resistance by a change of length has developed during the last few decades into a very important, versatile and widely distributed technique.

### Pressure monitor for pressure chute

The early difficulties which were experienced in Australia of frequent breakages of pressure chutes led to the development of a device for measuring the internal pressure of the chute. In its final form, this device consisted of a displacement transducer mounted on a beam and arranged to measure the deflection of the chute in the centre of either the top or bottom plate of the chute (Shann<sup>1</sup>). This is shown in Figure 1.

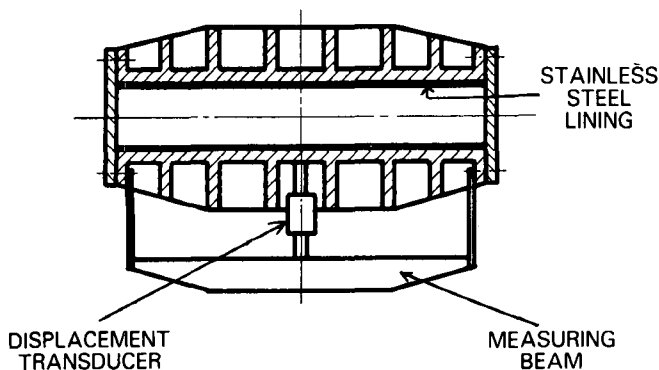


FIGURE 1 Section through "Walker" type pressure chute

This pressure monitor was sensitive to the ingress of dirt and moisture, and required constant attention from instrument staff to keep it operating satisfactorily. However, the monitor was found to be not only a valuable alarm to warn of increasing pressure, but also a useful tool to assess the performance of the mill as a whole.

Various alternatives have been tried over the years, but with little improvement. The new generation of pressure chutes as fitted at Felixton II (FX2), AK and MS, has been strengthened to such an extent that it is impossible to measure internal pressure by means of chute deflection, and for some years, they have been operated quite satisfactorily, but with no indication of internal pressure (see Figure 2).

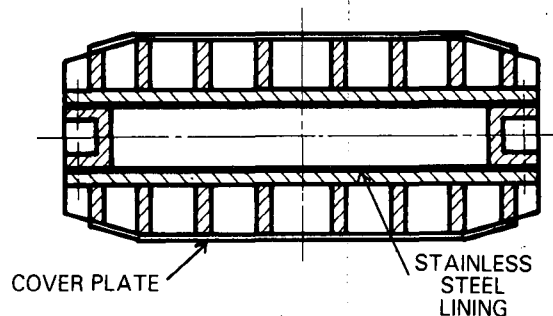


FIGURE 2 Section through "Amatikulu" type pressure chute

The chutes and their attachments are sufficiently robust to ensure that no breakage occurs. However, the absence of a "performance monitor" has been felt, particularly where the moistures obtained from diffuser dewatering mills have not come up to expectations.

### Development of a diaphragm monitor

These factors have led to the development of a stainless steel diaphragm built into the pressure chute and forming part of the lining plate. This diaphragm is fitted with strain gauges arranged to measure strain which is directly proportional to pressure (see the Appendix). The diaphragm has been fitted into the centre of one side of the pressure chute and attached to the backing plate, with countersunk set screws. A hole has been cut into the backing plate for access to the back of the diaphragm. This can be seen in Figure 3.

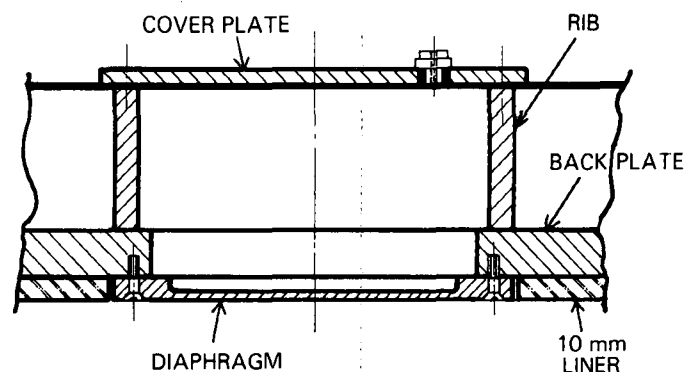


FIGURE 3 Enlarged section of diaphragm

An additional feature of the prototype diaphragm is the complete sealing of the back into a box formed by the strengthening ribs of the pressure chute. This box is maintained at a slightly positive pressure, using regulated instrument air. This feature also provides a convenient means of calibrating the diagram against a known accurate pressure.

The strain gauges are located on the diaphragm in such a way that two gauges at the centre are in tension, and two at the outer edge are in compression (see Figure 4).

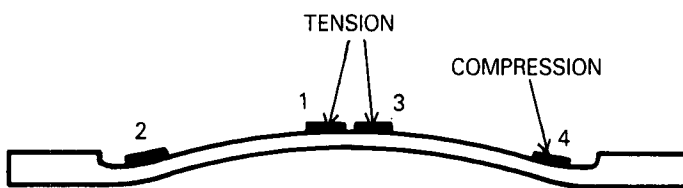
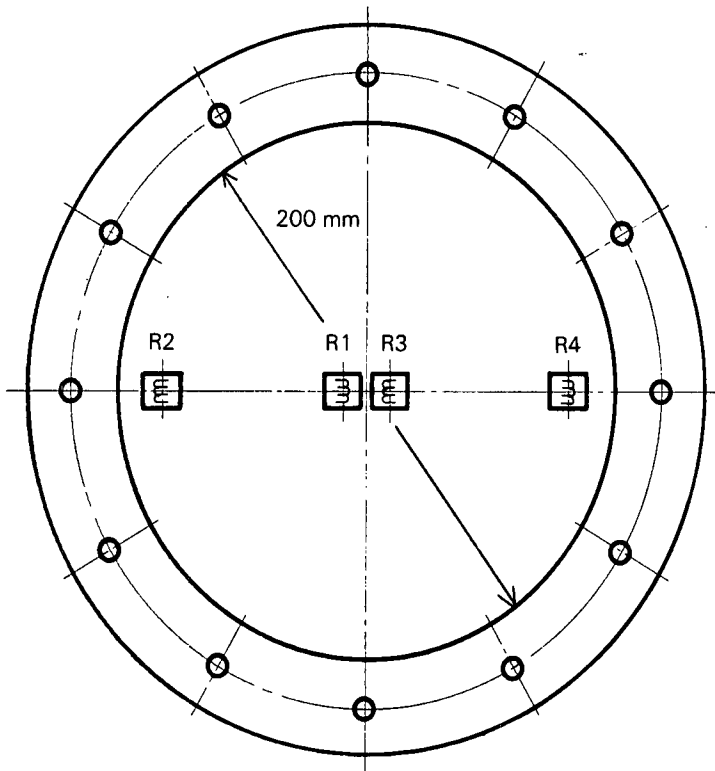


FIGURE 4 Detail of diaphragm

When these gauges are correctly connected into a Wheatstone bridge (see Figure 5), the change in output voltage is positive for all four gauges, and the sensitivity of the diaphragm is maximized.

The diameter and thickness of the diaphragm are chosen so that the stress is high enough to give a reasonable strain reading, and to provide coverage of sufficient area inside the pressure chute.

#### Operation

The prototype diaphragm was installed on the MS dewatering mill and has been working satisfactorily since 1 May 1984. The calibration of the diaphragm by air pressure was compared with the expected output derived by calculation and was found to be within 8%. The calculation is given in the Appendix.

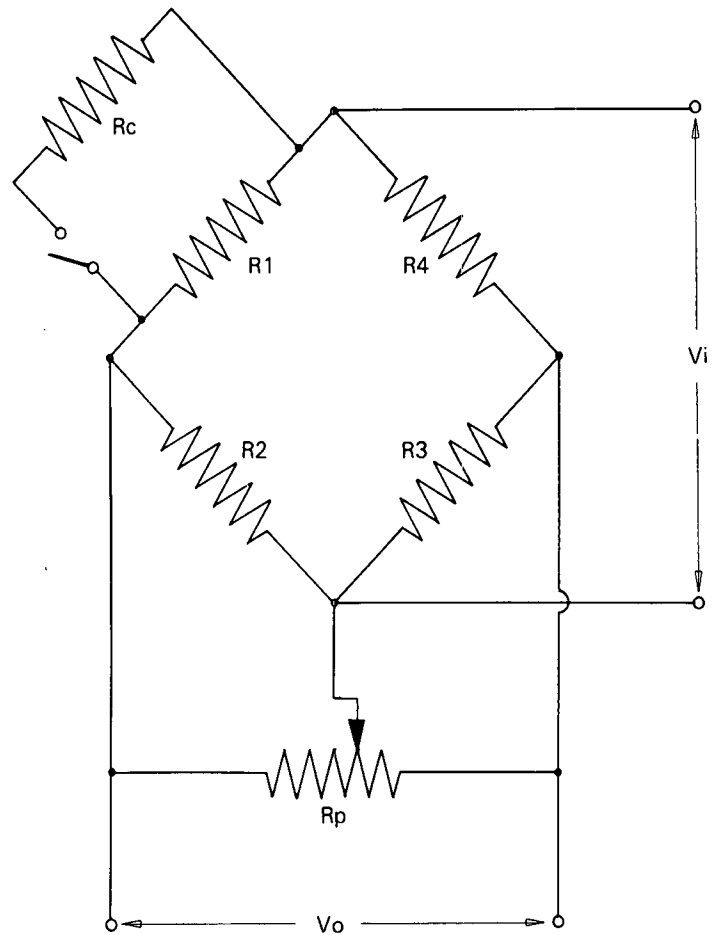


FIGURE 5 Strain gauge position in bridge

The amplified signal from the diaphragm is sent to a recorder graduated from 0 to 200 kPa. The trace on the recorder, a copy of which is shown in Figure 6, shows a large variation in signal from 0 to peak readings which vary from 40 to 200 kPa. The variation is attributed to the uneven nature of the compressed bagasse, which would deform the diaphragm into non-uniform shapes, thus subjecting the strain gauges to uneven strain. However, the peak reading is considered to be a true indication of internal pressure, and it is that which is of interest.

Experience with the monitor has shown that it can be used to warn the observer that all is not well in the mill. As an example, the trace in Figure 6 shows a situation before and after adjustment of trash plates and scrapers.

#### Torque Measurements

Torque measurements were carried out on the tail bars of mill and pressure feeder rolls of dewatering mills at AK, SZ and MS. It was decided to use strain gauges as opposed to displacement transducers thus avoiding cyclic fluctuations at rotational frequency from the torque signal, a phenomenon described by Jenkins and Jorgensen<sup>2</sup>.

Torque causes maximum strain at angles of plus and minus 45 degrees with respect to the axis of the shaft. In the case of a square shaft this strain occurs at the middle of the sides of the cross section. The strain in these two directions is of the same magnitude but of opposite polarity. Strain gauges were located in these directions on two opposite sides of the shaft (see Figure 7).

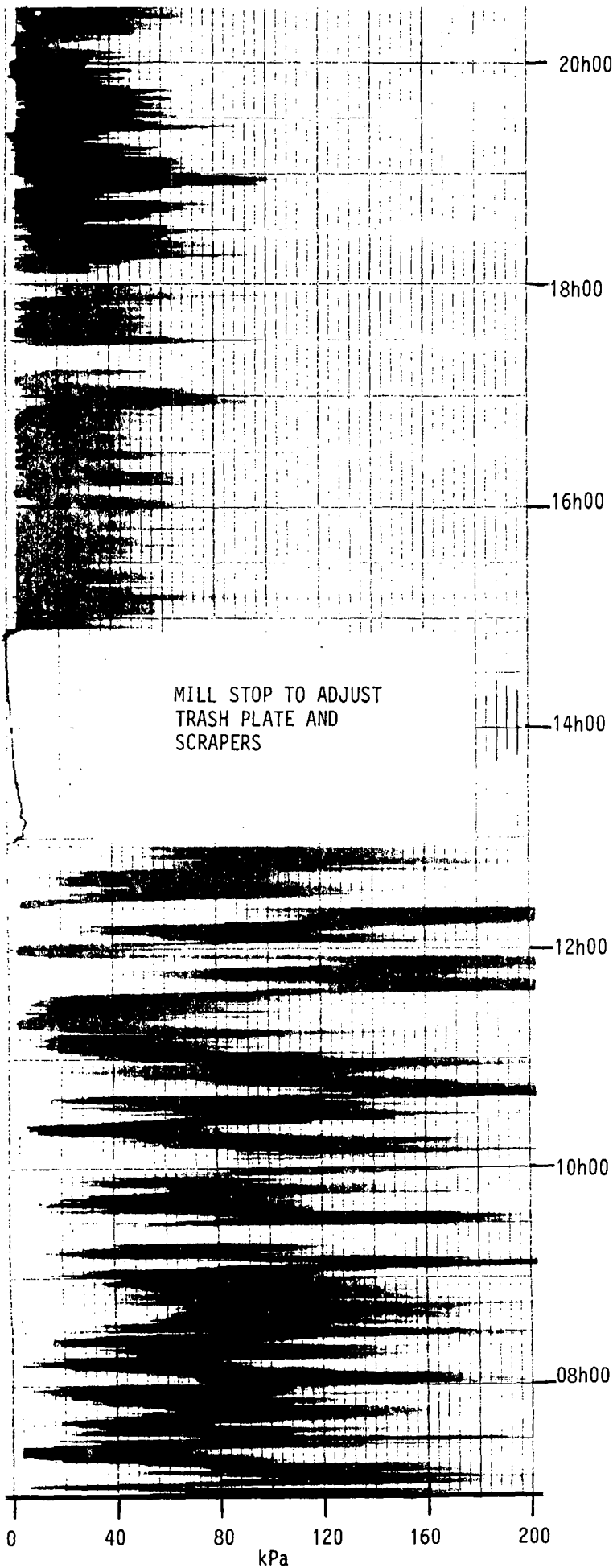


FIGURE 6 Chute pressure measurements at Maidstone

The four strain gauges were connected in a Wheatstone bridge in such a way that maximum bridge output voltage was achieved together with compensation for bending moment and temperature changes. For calibration purposes the bridge was equipped with a potentiometer and a fifth resistor parallel with one of the strain gauges (see Figure 5). The relationship between strain, bridge output voltage and torque is given in the Appendix.

FM telemetry equipment was used to transmit the bridge output voltage to a recorder. This system is very similar to the system described by Reichard and Vidler<sup>3</sup>. It consists of a battery, a transmitter and an aerial all fixed on and rotating with the shaft, and a receiver and an amplifier free from the shaft. The battery provides both bridge and transmitter with its energising voltage. The transmitter converts the bridge output voltage into a proportional pulse frequency. Although this frequency is almost independent of the battery voltage, a voltage regulator was installed to ensure a constant voltage of 12 V. The aerial transmits the pulses to the aerial plate of the receiver from where they are sent to the amplifier. The amplifier provides the receiver with its supply voltage, converts the modulated pulse frequency to a DC voltage and amplifies the signal. The signal was subsequently passed to a recorder and registered.

The telemetry equipment was found to operate satisfactorily at the Sugar Milling Research Institute but not at the mill. The receiver hanging in the hot saturated atmosphere most of the time was sensitive to the ingress of moisture and did not function on several occasions. This problem was overcome by putting the receiver in a water tight plastic bag filled with silica gel as a drying agent.

In order to relate the power absorbed by the mill to the fibre throughput, simultaneous measurements of the latter were made when possible. This was done in different ways, based on expressed juice, based on crushing rate and based on mill roll lift. The first two methods were giving satisfactory results but their application depends on the arrangement of the dewatering unit. The third method did not always give the results which could be expected, mainly due to difficulties in finding the correct reabsorption coefficient and to the use of unsuitable lift indicators. The application of this method is however to a large extent independent of the dewatering arrangement.

*Operation*

At AK the bagasse is split into three possible dewatering mills, of which two are generally used. The test mill which has been described by Van Breda<sup>4</sup> is equipped with a spikey-tooth pressure feeder. Hydraulics are fitted on the top roll and the discharge roll is fixed. Mill and pressure feeder torque were measured at different speeds and hydraulic loads. The fibre throughput was calculated based on expressed juice and on mill roll lift giving similar results. The power absorbed by the pressure feeder was about 9% of the total power. The absorbed power per ton of fibre was found to be between 7,5 and 8,5 kW t<sup>-1</sup> fibre h<sup>-1</sup>. The results are shown in Table 1.

TABLE 1  
Amatikulu results

Mill roll			Pressure feeder roll			Hydr. load (kN/m)	Fibre throughput (t/h)
Speed (rpm)	Torque (kN/m)	Power (kW)	Speed (rpm)	Torque (kN/m)	Power (kW)		
1,45	1287	195	2,00	92	19	2404	26
1,94	1277	259	2,67	90	25	2404	35
2,61	1225	335	3,64	92	35	2404	49
1,40	1345	197	1,94	109	22	2938	26
1,97	1340	276	2,73	97	28	2938	36
2,61	1345	368	3,64	88	33	2938	52

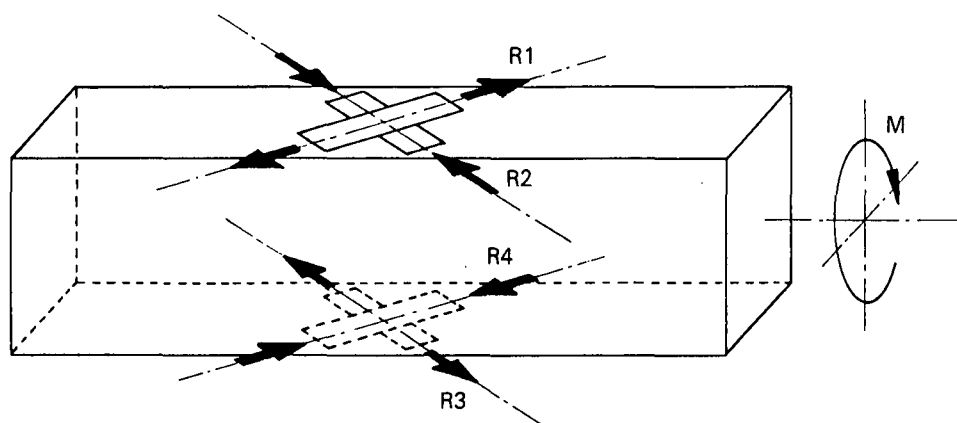


FIGURE 7 Strain gauge position on shaft

At SZ each diffuser is equipped with two six roll pressure fed mills, bagasse being fed in parallel. Tests were carried out on the first dewatering mill. The SZ mills are fitted with discharge roll hydraulics and fixed top roll. Torque measurements were carried out on both mill and pressure feeder roll at different speeds. Initially the fibre throughput was calculated from mill lift. However, this was giving results much lower than could be expected. A second test was carried out using only one mill so the fibre throughput could be calculated from the crushing rate figures. During that test the hydraulic load was slightly lower. The power absorbed by the pressure feeder was 30% of the total power absorbed and did not change with speed. The absorbed power per ton of fibre at a mill speed of 2,7 rpm was found to be approximately  $14 \text{ kW t}^{-1} \text{ fibre h}^{-1}$ . The results are given in Table 2.

TABLE 2  
Sezela results

Mill roll			Pressure feeder roll			Hydr. load (kN/m)	Fibre throughput (t/h)
Speed (rpm)	Torque (kN/m)	Power (kW)	Speed (rpm)	Torque (kN/m)	Power (kW)		
1,40	990	145	1,82	328	63	1792	—
1,97	869	179	2,55	292	78	1792	—
2,50	915	240	3,24	288	98	1792	—
2,69	991	279	3,47	323	117	1604	28

The MS diffuser has a single dewatering mill with a two roll, Walker type, pressure feeder and an auxiliary feed drum. Hydraulics are fitted on the top roll as well as on the discharge roll. Torque was measured on mill and pressure feeder roll at various speeds but at a constant hydraulic load. No measurements of the fibre throughput were carried out. The power absorbed by the pressure feeder was about 30% of the total power and independent of speed. The results are to be seen in Table 3.

TABLE 3  
Maidstone results

Mill roll			Pressure feeder roll			Hydr. load (kN/m)	Fibre throughput (t/h)
Speed (rpm)	Torque (kN/m)	Power (kW)	Speed (rpm)	Torque (kN/m)	Power (kW)		
3,44	858	309	4,50	269	127	1710	—
3,96	800	332	5,22	240	131	1710	—
4,47	835	391	5,81	261	159	1710	—

In most cases the torque for both mill and pressure feeder roll was hardly affected by a change of speed. This means that power and fibre throughput are directly proportional to the speed. It was found that mill lift was decreasing with increasing speed which means an increasing reabsorption coefficient. Although not indicated clearly by the figures given above it was found that an increase in hydraulic load resulted in an increase of the torque drawn by the mill roll without affecting the pressure feeder torque (see Figure 8).

Because of that the power absorbed by the pressure feeder as a percentage of the total power decreases with an increase in the hydraulic pressure.

### Conclusions

This work has demonstrated the effectiveness and simplicity in the use of strain gauges both for research work and also for instrumentation operating under normal sugar milling conditions.

The diaphragm has been successfully tested as an effective pressure chute monitor, under normal operating conditions on a diffuser dewatering mill. The installation has required no maintenance at all, and the only problem has been a zero drift of about 1%, which has been attributed to physical wear of the diaphragm.

It is feasible to consider the application of this monitor to control the pressure feeder, where such control is possible. For example, if the mill and pressure feeder are driven by separate variable speed drives, the speed ratio between the two could be controlled by the pressure monitor, where an increase in pressure will decrease the relative speed of the pressure feeder rolls.

The results of the initial torque measurements represented above have shown that the acquisition of the telemetry based torque measuring equipment has provided a quick and reliable technique for measuring mill input power. The information obtained will be used in further work on the optimisation of dewatering mill performance.

### Acknowledgements

Thanks are due to the staff of the AK, SZ and MS mills for their contributions to this project.

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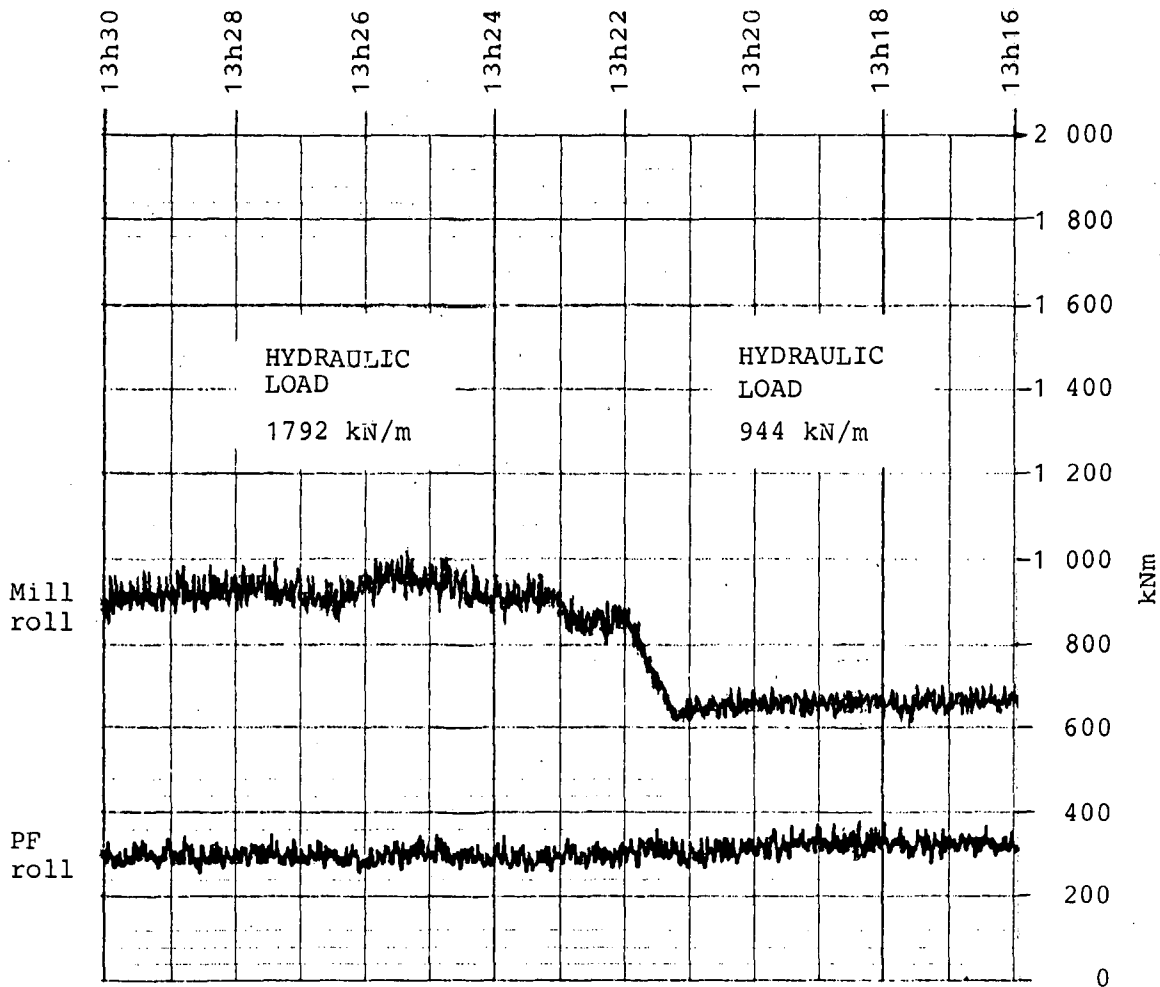


FIGURE 8 Torque measurements at Sezela

APPENDIX

Calculations of strain gauge output

The output voltage  $V_o$  of the Wheatstone bridge is given by:—

$$V_o/V_i = K_s (e_1 - e_2 + e_3 - e_4)/4$$

where  $V_i$  = input voltage

$K_s$  = gauge factor

$e$  = strain on each gauge.

Pressure diaphragm

The radial strain at any radius  $r$  on a diaphragm is given by:—

$$e = \frac{3pa^2}{8m^2E} \left( (3m+1)\frac{r^2}{a^2} - (m+1) \right)$$

- where  $p$  = pressure = 200 kPa maximum
- $a$  = outside radius of diaphragm = 100 mm
- $m$  = reciprocal of Poisson's ratio = 0,3 for steel
- $t$  = thickness of the diaphragm = 4 mm
- $E$  = Young's modulus =  $207 \times 10^6$  kPa

The two inner gauges 1 and 3 are placed at  $r = 6$  mm and outer gauges 2 and 4 are placed at  $r = 89$  mm

The calculation yields an output at a maximum of:—

$$V_o/V_i = 0.647 \text{ mV/V}$$

On calibration, an output of 0.6 mV/V was measured, which was the limit of accuracy of the voltmeter being used.

Torque measurements

The strain on a circular shaft at an angle of  $45^\circ$  with respect to the axis of the shaft is given by:—

$$e = \frac{8 \times M}{\pi \times G \times d^3}$$

The strain on a rectangular shaft at an angle of  $45^\circ$  with respect to the axis, measured at the middle of the sides of the cross section is given by:—

$$e = \frac{8 \times M}{3,328 \times G \times a^3}$$

- where  $M$  = torque Nm
- $G$  = shear modulus  $\text{Nm}^{-2}$
- $d$  = diameter of circular shaft m
- $a$  = side of shaft m