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Borisson, Ulf; Syding, Rolf

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LUND UNIVERSITY

PO Box 117
221 00 Lund
+46 46-222 00 00

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CONTROL OF AN ORE CRUSHER - A FEASIBILITY STUDY OF SELF TUNING CONTROL AND REMOTE PROCESSING

U.BORISSON
R.SYDING

TILLHÖR REFERENSBIBLIOTEKET
UTLÅNAS EJ

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Division of Automatic Control

CONTROL OF AN ORE CRUSHER - A FEASIBILITY STUDY OF SELF TUNING CONTROL AND REMOTE PROCESSING.

U. Borisson R. Syding

ABSTRACT.

This report describes an application of a self tuning regulator. The work was carried out both for the purpose of investigating the feasibility of self tuning regulators for industrial processes and for the purpose of providing experience on the use of real industrial processes for research and education in Automatic Control. An ore crusher in Kiruna was controlled by tele processing from the computer at the Division of Automatic Control in Lund. The data transmission distance was about 1800 km. The process is characterized by long transport times and varying types of disturbances. The experiences of the self tuning regulator were good, and the technique to use tele processing for remote control experiments turned out to be successful.

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1. INTRODUCTION

Control of ore crushers involves some characteristic problems due to special process dynamics and considerable transport times. The purpose of the control is to keep the production on a certain level, as high as possible, without overloading the crusher.

The work presented here has been done in cooperation with LKAB, Kiruna. The purpose was to study the feasibility of controlling an ore crusher at the ore crushing plant in in Kiruna, Kiruna Finkrossverk, with a self tuning regulator and to test the technique of using tele processing for remote control experiments.

Before the on-line experiments started a pilot study was done. Data from the crusher plant were registered and a model of the process was determined with a maximum likelihood identification method. This model was then used in simulations with the self tuning regulator. The results of the simulations were promising, and it was decided to make on-line experiments from the computer at the Division of Automatic Control in Lund.

The self tuning regulator has previously been used in industrial process control on paper machines, where the moisture content of paper has been controlled successively [3]. A theoretical background of the algorithm is given in [2] and [4]. The practical arrangements are described in [1]. The data signals were transmitted about 1800 km.

This report is organized as follows. A description of the crusher plant is presented in section 2. In section 3 some comments on the process disturbances are given. The hardware facilities for the experiments are shortly described in section 4. In section 5 the design of the regulator is discussed.

Some experiments are described in section 6 and registrations from the control are given. The experiences are summarized in section 7, and the conclusions are given in section 8. In the appendix time plans and experiment costs are presented.

2. THE CRUSHER PLANT

In the mine the ore is first coarsely crushed to lumps with a thickness less than 10 cm. Then it is transported to a crusher plant where it is finely crushed to lumps with a thickness less than 2.5 cm. There are six crushers in the plant. One of these was used in the experiments.

2.1 Description of the crusher.

The crusher is of conical type and the mark is "Symons". Fig. 2.1 describes how it works.

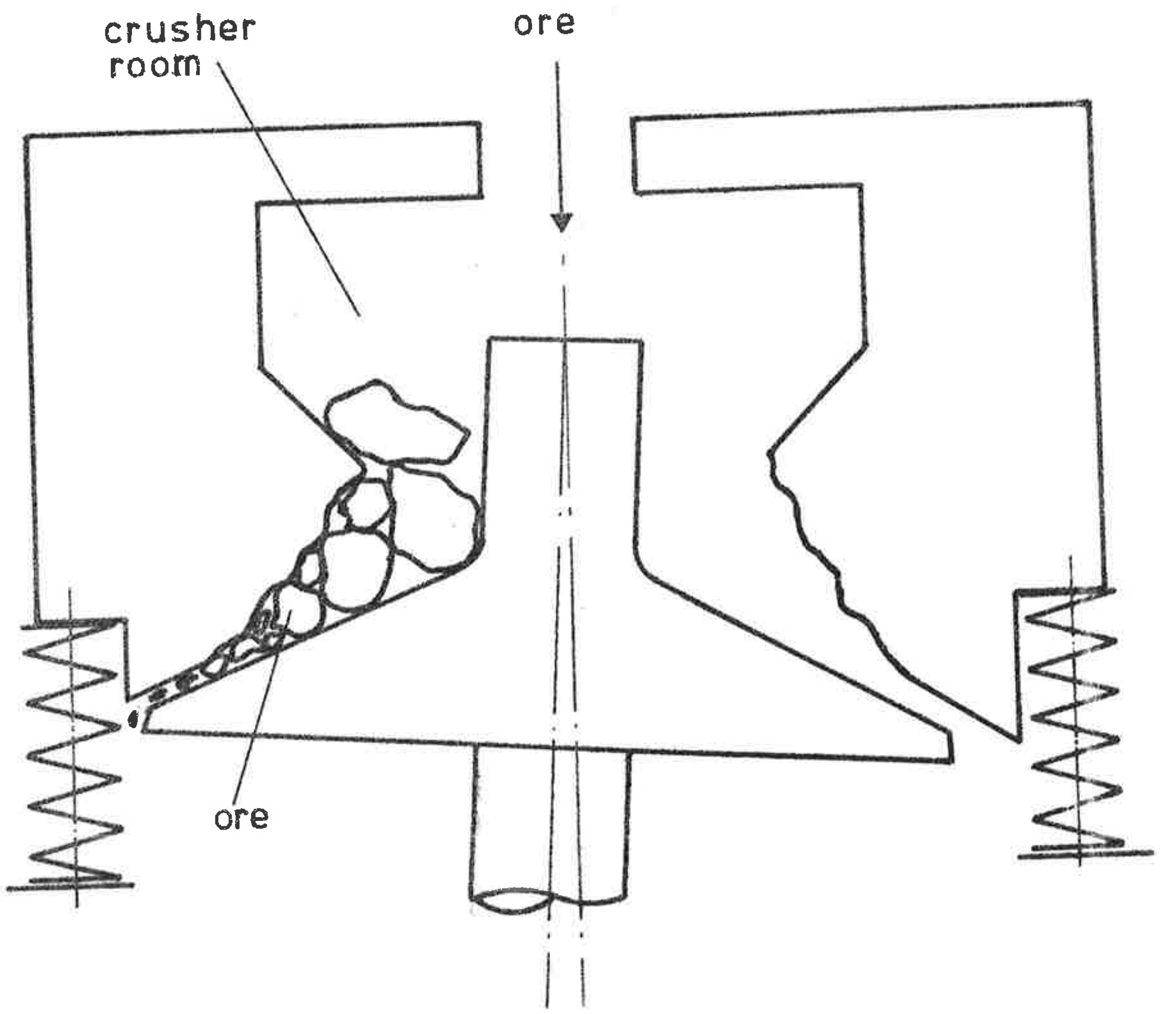


Fig. 2.1 Schematic figure of the crusher.

The crusher axis performs a circling movement with almost no rotation at all. The goods is spread in the crusher room, where the ore lumps are crushed between the jackets. In the lower part of the crusher room the jackets are parallel and the distance between them is 2.5 cm. The jackets must be replaced by new ones at intervals of about three months, as they get worn-out. There is a special slip coupling which limits the moment of the crusher axis. If the moment becomes too great, the crusher motor is switched off.

A block diagram of the plant is given in fig. 2.2. A feeder of vibrating type transfers the ore to a transport band, which passes a belt scale. At screen I small ore lumps are separated. The rest goes to the crusher loop. The maximum capacity of the feeder is about 2000 ton/h. The transport time between feeder and crusher is 42 seconds, and it takes 74 seconds for the ore to pass around the crusher loop. The ore remains in this loop until it is crushed so much that it is separated at screen II.

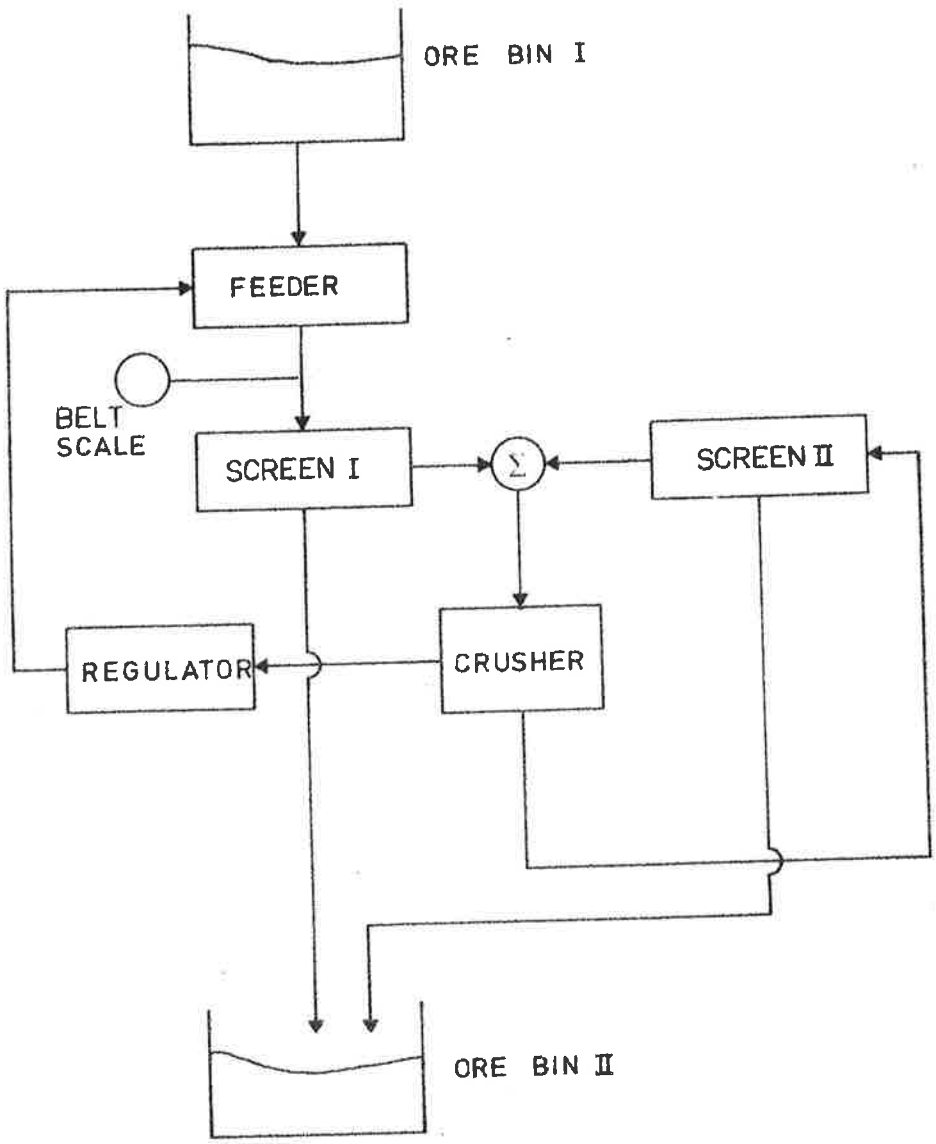


Fig. 2.2 - Flow chart of the ore crushing plant.

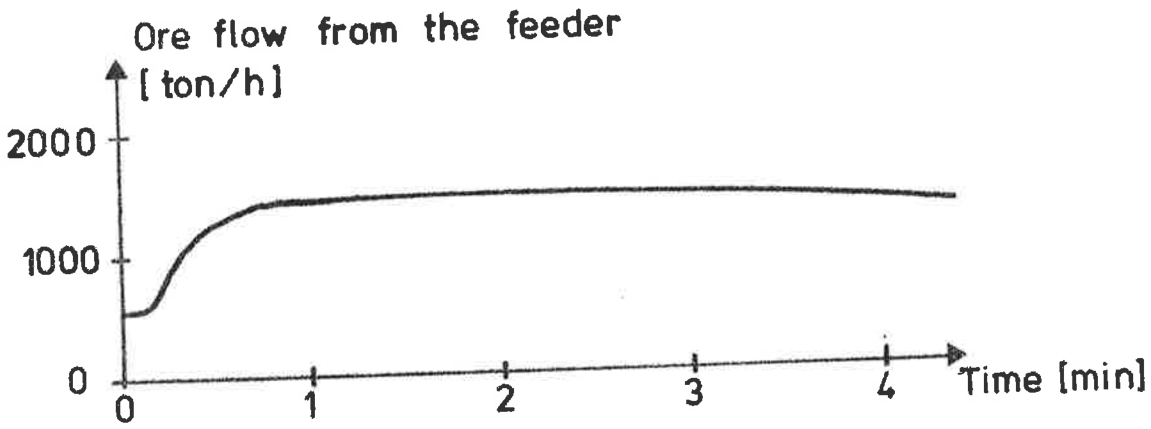
2.2 Plant Dynamics.

An experiment was made to study the step response of the crusher. The result is shown in fig. 2.3. The reference value of the feeder was changed as a step. The ore flow from the feeder is given in fig. 2.3.a. The feeder may be approximated by a first order system. Fig. 2.3.b shows the resulting crusher power. It indicates that the system with the reference value of the feeder as input and the crusher effect as output may be approximated by a second order system with a time delay that is a little more than 40 seconds. The crusher itself can then be described by a first order system. Its time constant is about 20 seconds. The time constant of the feeder is shorter, about 12 seconds.

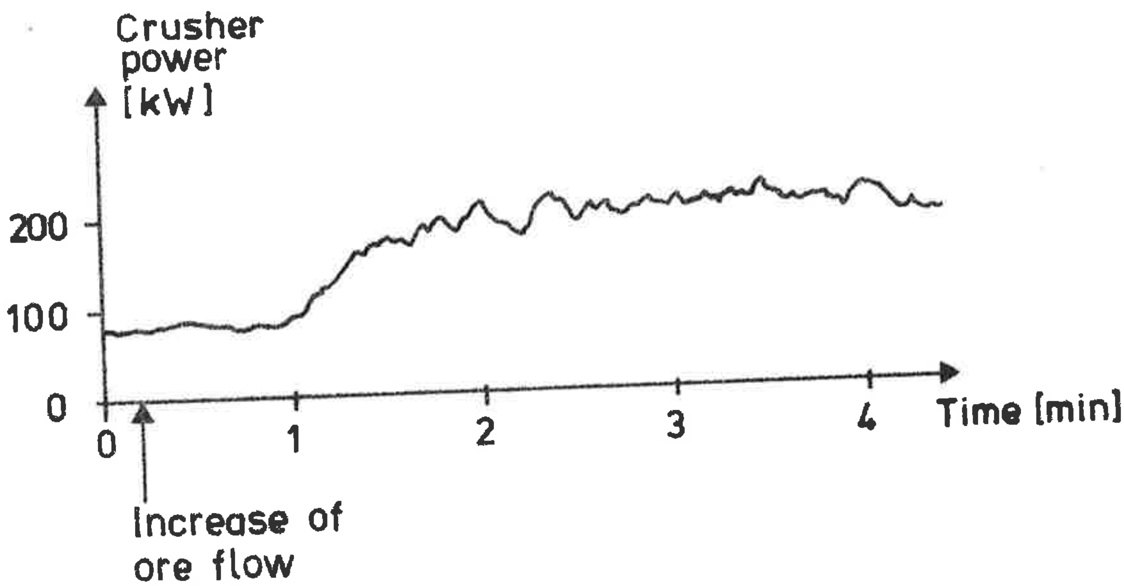
Sometimes the process behaves differently, e.g. if the ore is hard. Fig. 2.4 gives an example. The ore flow from the feeder has been increased, and the crusher does not manage to crush it fast enough to avoid that the ore accumulates in the crusher loop. The power then becomes very high.

2.3 The ore.

The ore, which mainly consists of magnetite, is transported to ore bin I in batches. When the bin is filled, small ore lumps gather at the bottom. This variation in the sizes of the ore lumps makes the crusher more difficult to control. There may also be a variation in the composition of the ore. Sometimes it contains much waste rock, and then it is hard to crush.



a.



b.

Fig. 2.3 - Step response experiment I.

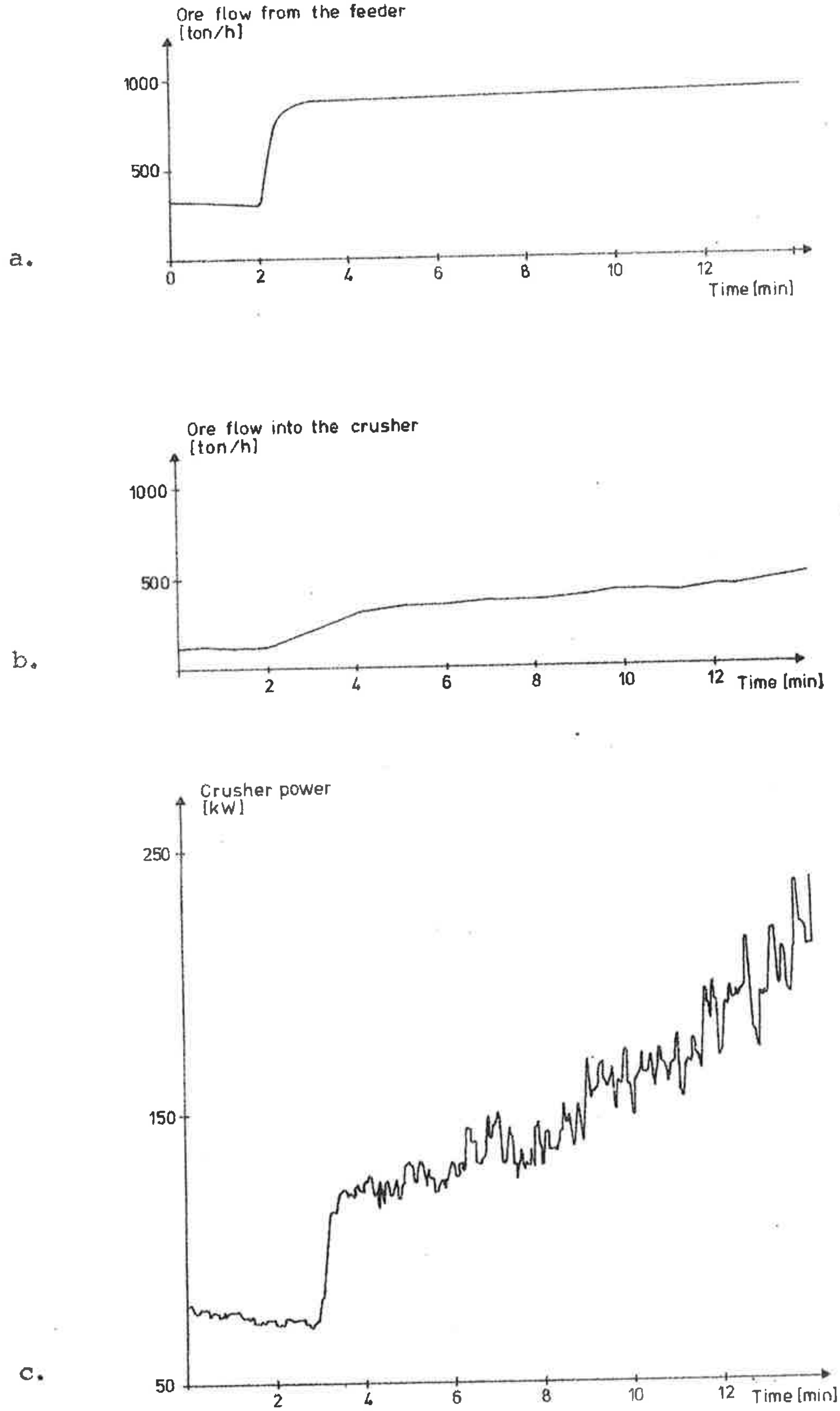
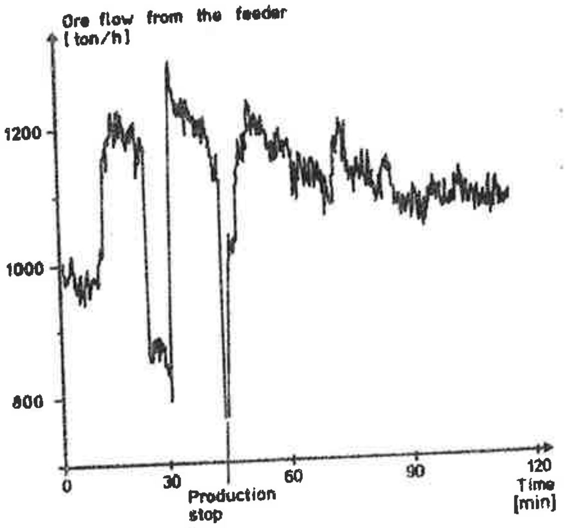


Fig. 2.4 - Step response experiment II.

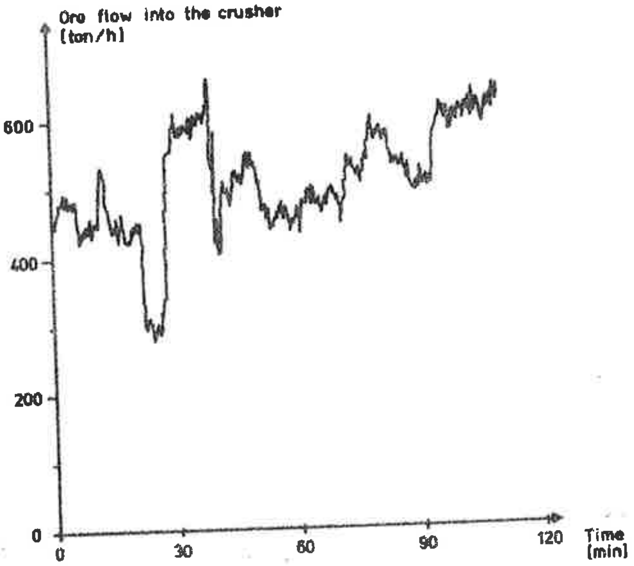
3. PROCESS DISTURBANCES.

The purpose of the crusher control is to make it possible to get a high production. Different kinds of disturbances always influence the process, and the regulator has to compensate for these. The crusher gets overloaded if the power is too high. Then it is stopped automatically, and the ore in the crusher must be removed. When the process is started up again, it takes some time before full production can be achieved.

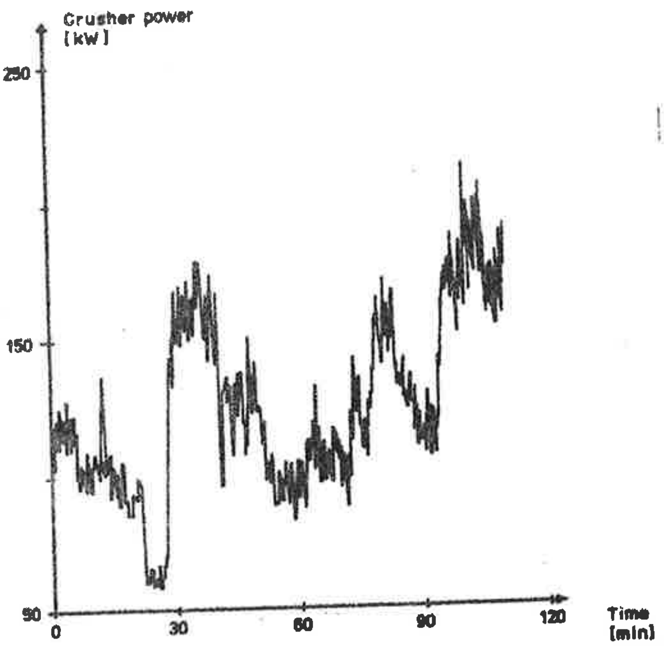
The variations in the raw material cause special problems at the control. To get an idea of the disturbances an experiment was made with a constant reference value to the feeder. No regulator was connected to the process. The result of the experiment is given in Fig. 3.1, where the total ore flow from the feeder, the ore flow into the crusher and the crusher power are shown. One problem is that it is never known how much of the ore that will be separated at screen I (see Fig. 2.2). The ore flow into the crusher is thus varying and this influences the power. Other disturbances in the power depend on variation in the sizes of the ore lumps and inhomogenities in the ore composition. In Fig. 3.1c the mean value of the power is 161 kW, while the minimum value is 92 kW and the maximum value is 228 kW. The higher the set point of the power is, the harder will it be to control the process.



a.



b.



c.

Fig. 3.1 - Experiment without any control of the crusher.
The reference value of the feeder is constant.

4. HARDWARE FACILITIES.

A schematic description of the DDC loop is shown in Fig. 4.1. A detailed presentation is given in [1].

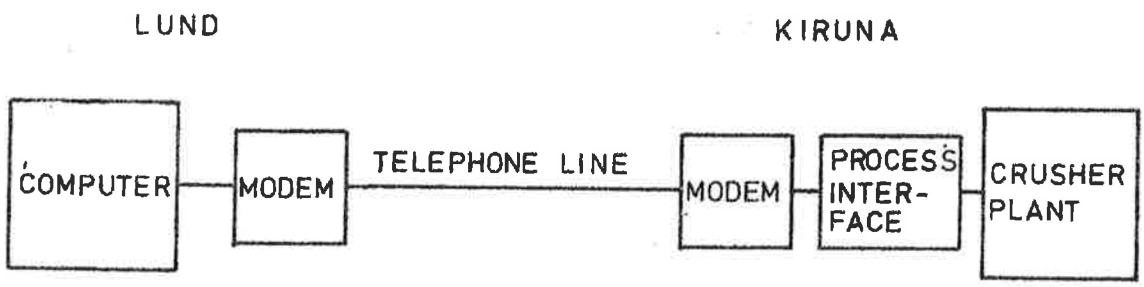


Fig. 4.1 - The DDC loop.

The self-tuning algorithm was implemented on a PDP 15 computer in Lund. Low speed modems and a public telephone line were used for the data transmission. The process interface includes a remote control terminal where D/A conversion was performed.

5. REGULATOR DESIGN

The crusher is usually controlled by an analog PI regulator. As the transport time in the plant is considerable and as special problems sometimes arise when ore is accumulating in the crusher loop, the PI regulator cannot always give a good result.

With a digital regulator it is easier to compensate for the dead time in the process. It is also easier to choose a structure of the regulator that is better suited to the properties of the process. One problem with a more complex regulator is to find proper parameters. In a situation like this a self tuning regulator may be useful. This regulator tunes its parameters automatically on-line and the structure can be chosen arbitrarily. In Section 6 some results from the experiments with the self tuning regulator are presented.

The regulator design is based upon the available information about the process. Investigation of the process dynamics shows that 20 seconds may be a suitable sampling interval. A detailed description of the self tuning regulator is given in [2] and [4]. Some aspects on the practical use are also given in [3]. The general structure of the regulator can be written

$$\Delta u(t) = \frac{1}{\beta_0}[\alpha_1 y(t) + \ldots + \alpha_m y(t-m)] - \beta_1 \Delta u(t-1) - \ldots - \beta_\ell \Delta u(t-\ell)$$

where $\Delta u(t)$ is the incremental control signal and $y(t)$ is the output from the process. β_0 is a constant.

The algorithm requires information about the number of alfa and beta parameters and the number of time delays in the process. Then it estimates the optimal values of the alfa and beta parameters. The rate of convergence in the beginning of the estimation is influenced by a weighting factor which is an exponential function with the base λ. Normal values of λ are 0.95 - 1. The closer λ is to 1, the smaller will the step length at the parameter estimation be.

As was pointed out in Section 2 the transport delay is 42 seconds between feeder and crusher and 74 seconds in the crusher loop. With a sampling interval of 20 seconds there are 2 - 3 time delays between feeder and crusher and 3 - 4 time delays in the crusher loop. Different regulator structures were tested during the experiments. A regulator with three time delays, four alfa parameters and three beta parameters gave a good result. The choice of the number of alfa and beta parameters was not crucial. However, due to the long time delays in the process, the regulator seemed to benefit from a comparatively large number of alfa and beta parameters. After about twenty minutes from the start of the self tuning control the regulator parameters had generally stabilized at certain values.

6. EXPERIMENTS.

The ore crusher was in normal operation when the control experiments with the self tuning regulator were made. The control loop from Lund was connected to the crusher plant by a switch, which had been installed in Kiruna.

Two examples of self tuning control will now be discussed. In both cases the regulator had three time delays, four alfa parameters and three beta parameters. The weighting factor λ was 0.99.

Example 1.

In the beginning of the experiment the set point of the crusher power was 170 kW. It was then increased to 200 kW, and Figure 6.1 shows registrations from this part of the experiment.

The mean value of the crusher power in Fig. 6.1 a is 198.3 kW, which is near the set point (200 kW). The estimated standard deviation for this registration is 19.7 kW, which is a good result compared with conventional control at this power level. About 30 minutes after the start of the registration the crusher power is getting high. The self tuning regulator decreases the ore flow immediately, Fig. 6.1b. Fig. 6.1c shows the control signal (in mA) to the vibrating feeder.

The regulator parameters are shown in Fig. 6.1d. In the beginning of the registration they do not vary much. When the variations in the power become greater at the end of the registration, the parameters are changing more.

a.

b.

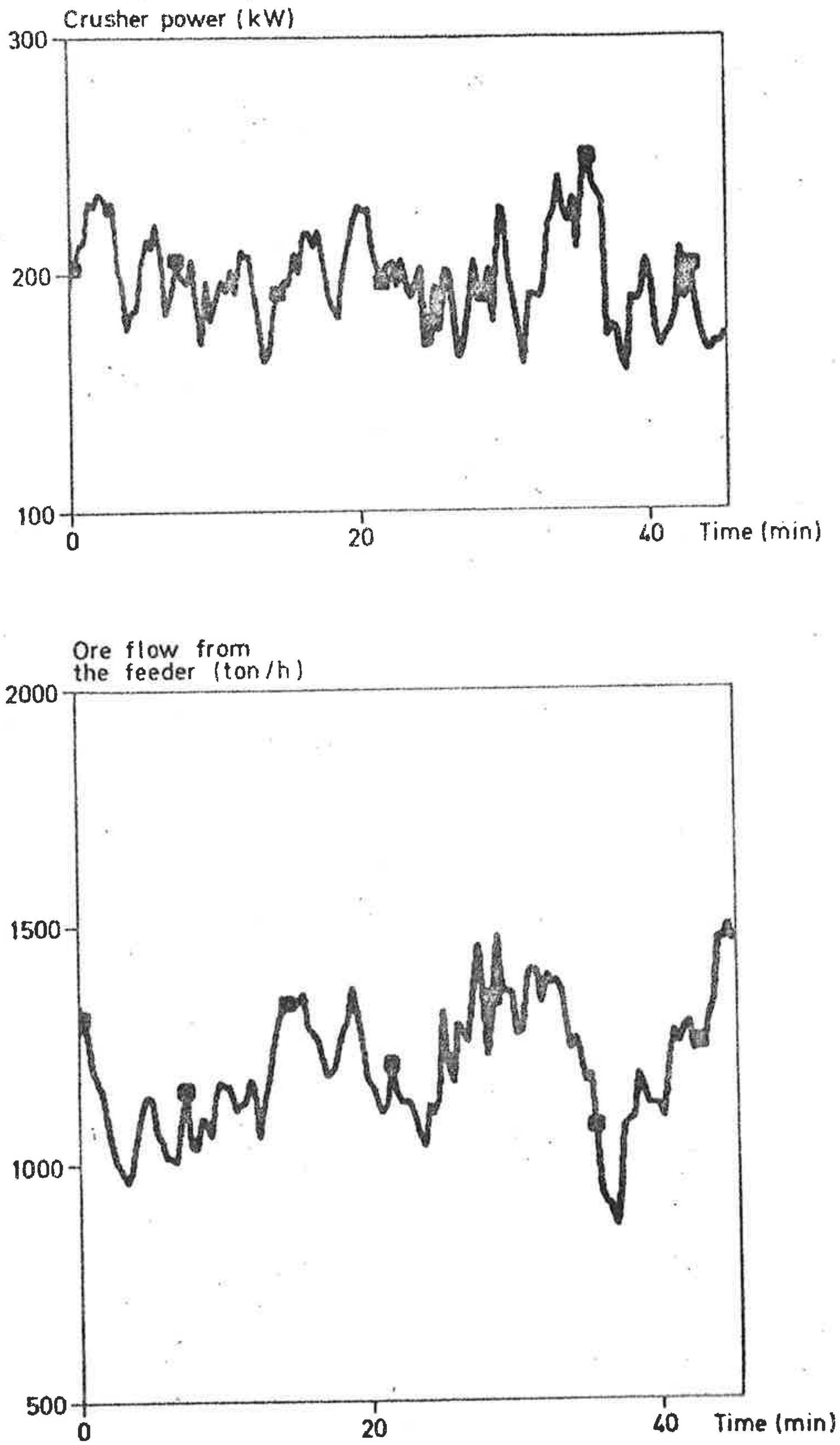
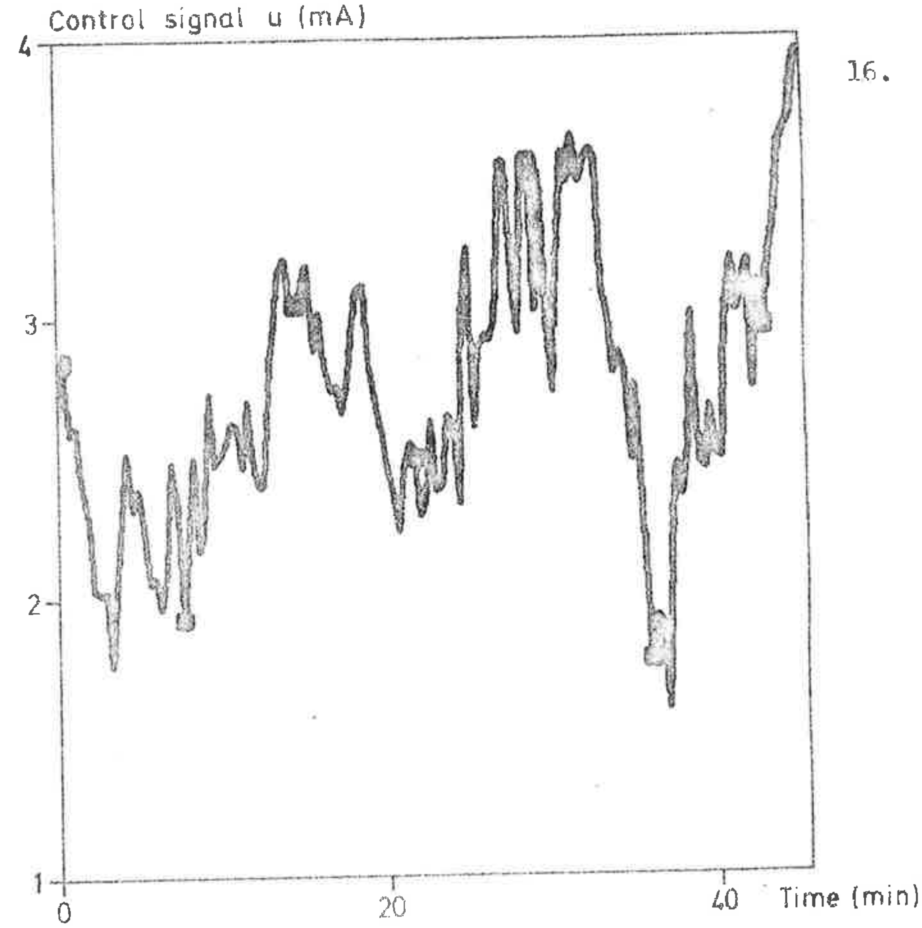
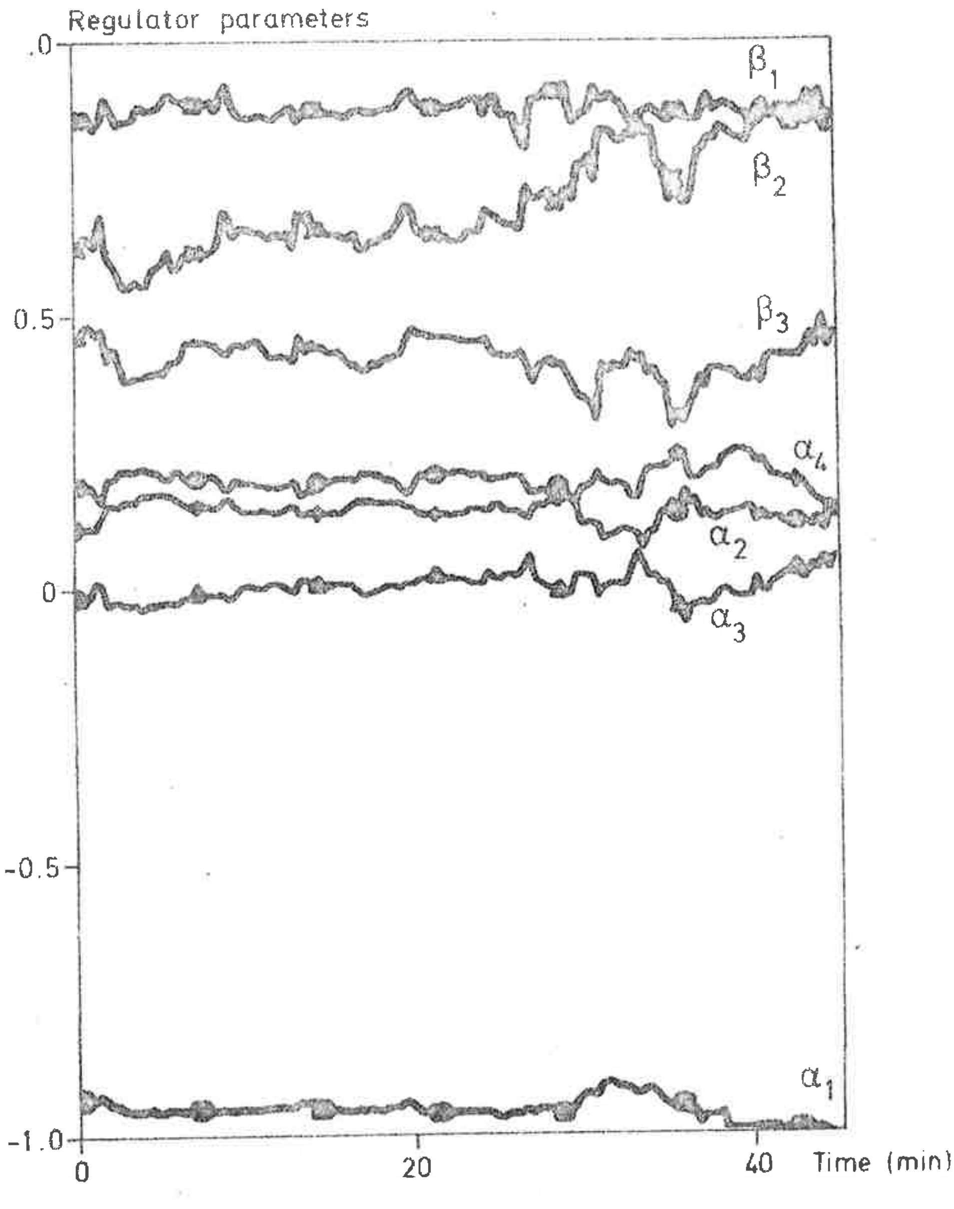


Fig. 6.1 - Control with self tuning regulator. Example 1.



c.



d.

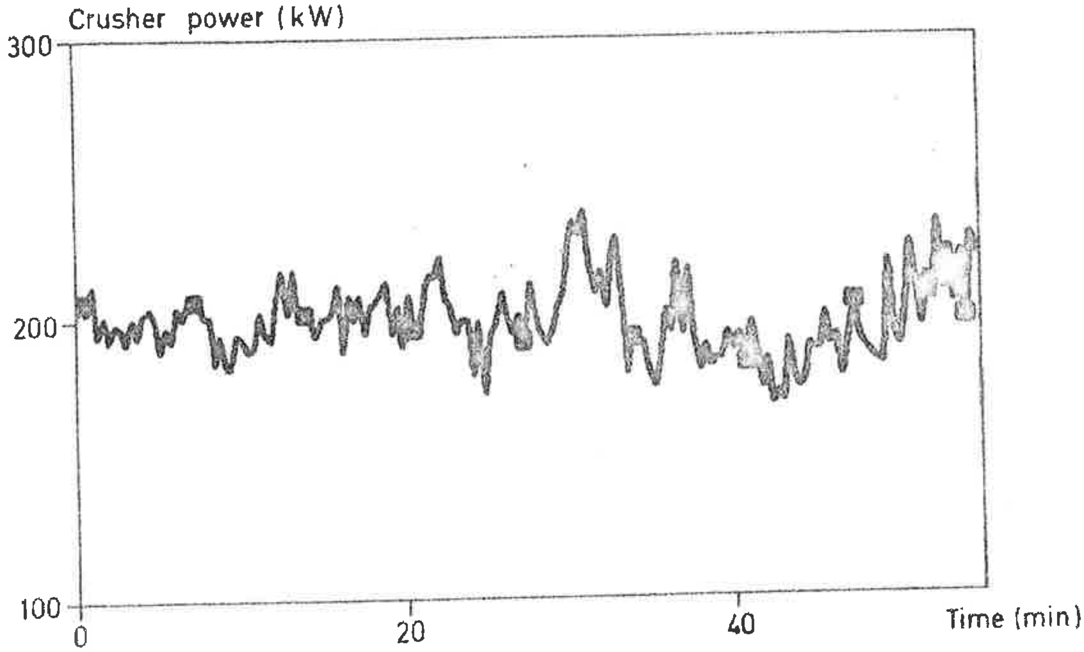
ig. 6.1 (cont'd) - Control
ith self tuning regulator.
xample 1.

Example 2.

This example shows what may happen when ore bin I is filled. Often there are many ore lumps that already are very small. These tend to gather at the bottom of ore bin I. When they arrive at screen I, they are separated and go directly to bin II. In this situation the feeder has to increase the ore flow to keep the crusher power at a constant level.

In Fig. 6.2b the ore flow is shown. About 40 minutes after the start of the registration bin I is filled with new ore. The feeder immediately increases the ore flow, so that the crusher power can be kept on about the same level, Fig. 6.2a The mean value of the crusher power is 199.5 kW and the estimated standard deviation is 13.3 kW.

a.



b.

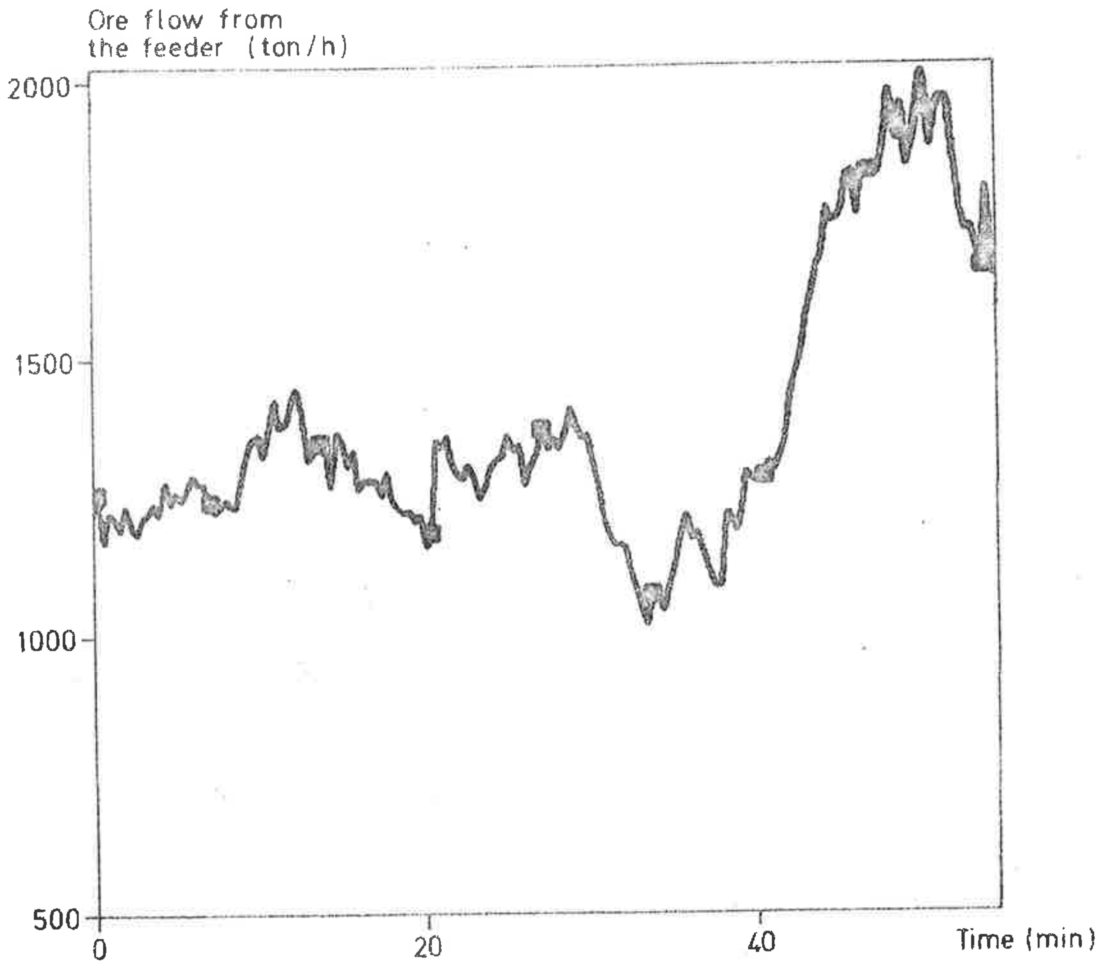


Fig. 6.2 - Control with self tuning regulator. Example 2.

7. EXPERIENCES.

The feasibility study showed that a self tuning regulator with good control properties could be designed for the ore crusher. It was possible to use a high set point for the crusher power, around 200 kW, thus giving a high production capacity. When a great disturbance influenced the process, the self tuning regulator gave a quick response.

The analog PI controller that usually governs the process has fix parameters. These can be changed manually. In practice, however, it is not possible to make a regular tuning of the parameters according to the conditions in the plant, since it would be too time consuming. A self tuning regulator is therefore valuable.

The set point of the analog PI controller is usually about 170 kW. The standard deviation of the crusher power is generally not as good as with self tuning regulator on the same power level. A detailed comparison is, however, hard to do, as it also should include experiments with longer run times than was possible to have within the scope of this study.

This work also gave some useful information about the crusher. At some occasions when the ore flow is large, the crusher room (see Fig. 2.1) may be filled to the top. Then the crusher is automatically switched off. This had not been a real problem before as the PI controller mostly worked with smaller ore flows than the self tuning regulator. It would be desirable to have an arrangement so that the ore flow is decreased before the crusher room is full.

The technique of using tele processing for remote control worked well. This study has shown that real industrial processes simply can be used for applied research in Automatic Control.

8. CONCLUSIONS.

During recent years LKAB has studied different possibilities to increase the efficiency of some of its production processes by use of small computers. Concerning the crushing plant it has been considered possible to increase the production capacity by computer control. A better supervision of some critical process variables should thus reduce the number of production stops and a control algorithm adequate to the process should allow an increase of the level of the crusher power. A computer should also make it possible to get a shorter start-up time to full production after a stop in the plant.

The study described in this report has concerned the control algorithm for the crusher. The results have shown that a self tuning regulator is well suited to handle the carachteristic features of the process. A high set-point of the crusher power can be used with good result.
The self tuning regulator is therefore recommended as control algorithm for the crusher.

9. ACKNOWLEDGEMENTS.

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APPENDIX

TIME PLANS AND EXPERIMENT COSTS.

The project with self tuning control of the ore crusher in Kiruna followed the following time plan.

Start of software development:	15 November, 1972
Start of on-line experiments:	1 December, 1972
Completion of the project:	15 February, 1973

Time consumption.

Construction of Remote Control Terminal:	0.5 man month
Software development and on-line experiments	
Lund:	1.5 man month
Kiruna:	0.5 man month

Computer time (software development and on-line experiments):	80 hours
Modem costs (two modems, each of them 440 kr/month):	2640 kr
Cost for telephone line:	2400 kr