VI INTERNATIONAL MEETING ON TITANIUM

THE DEVELOPMENT OF COMPUTER CONTROL IN TITANIUM SPONGE GRANULE MANUFACTURE

Peter Morcom
Deeside (UK)

THE DEVELOPMENT OF COMPUTER CONTROL IN TITANIUM SPONGE GRANULE MANUFACTURE

Ladies and Gentlemen, my name is Peter Morcom, and I am the Process & Systems Manager of Deeside Titanium Limited, or DTL for short.*

In the next 20 to 30 minutes, I will be discussing the introduction of computer control to the reaction process we employ at DTL to make titanium. Before I do this, I will briefly give details on DTL as a company, and also a resume of the process we use at DTL.

DTL started production in 1981 and is a subsidiary of Rolls-Royce plc with IMI plc as the minority shareholder. DTL produces titanium sponge granules of the highest quality, and these are mainly used in the high temperature titanium alloys manufactured by IMI and utilised in Rolls-Royce aero engines. IMI 834 is the latest high performance titanium alloy produced using DTL material and is used extensively in the Rolls-Royce Trent Engine.

In addition to granules, DTL produce a range of titanium powders.

The process we use is often call the Hunter Process, named after the person who first developed it, and is essentially the same process used previously at the ICI plant which DTL replaced.

The process consists of the following main steps; Raw Material Handling, Raw Material Purification, High Temperature Reaction between Sodium and Titanium Tetrachloride, Removal of product from the Reactor, Crushing, Leaching, Drying and Packing.**

---

* Fig. 1

* * Fig. 2

The main raw materials, Sodium and Titanium Tetrachloride (or TTC for short), are received in rail or road tankers and are stored on site. Both these materials then go through purification processes and are stored in measure vessels ready for introduction into the reaction process.

The reaction process is a batch process and is carried out in a leak tight argon filled enclosed reactor vessel which is placed in a gas heated furnace. Sodium is charged to this vessel and heated. TTC is fed into the vessel over a period of about 30 hours, and the temperature within the reactor can exceed 1000 degrees centrigrade during some stages of the reaction.

During the reaction, close control of process parameters, including reactor pressure, TTC flowrate and furnace conditions, is maintained.

At the end of the reaction, the reactor is transferred to a cooling bay, where water is sprayed onto the outside of the vessel whilst maintaining a positive argon pressure inside.

Once the reactor product (or melt) has cooled to ambient temperature, the melt, which consists of approximately 1 part of titanium to 5 parts of sodium chloride, is removed from the reactor and crushed. The salt is leached out leaving titanium granules which are then dried and packed into drums.

Today, I will be concentrating on the reaction stage of the DTL process.

The reaction process first used at DTL was manually controlled, and was a "Chinese Copy" of that which had been used previously at ICI.

The only process variable data available on the ICI reaction process was that given in their Process Operating Instructions and manually recorded on log sheets by process operators. The information was of limited use as only hourly readings were taken. Therefore, as the reaction process was considered to be critical to the quality of titanium produced, and also the part of the process about which least was known, DTL decided in 1980 to install a sophisticated data logging facility as a first step to introducing full computer control at some time in the future.

Development of the data logging system commenced in 1981 and continued through to early 1983, when the system became fully operational.

The next slide shows a schematic of the data logging system. The data logging system is still in full use, and has been much enhanced to log other process plant areas. The basic design concept, however, remains the same.[*]

Analogue and digital information tram instruments and control valves associated with each reactor station is collected at regular intervals by a Hewlett Packard mini computer. Weight information tram the sodium and TTC measure vessels is also logged.

Once a reaction batch has been completed the acquired data is compressed using pre-determined deadbands for each process variable monitored, and archived onta disc or tape. Data for each reaction batch will be kept for 25 years to satisfy aerospace requirements.

---

* Fig. 3

The next slide shows the types of reports and information available tram the data logging system.[*]

Any logged process variable can be displayed or plotted in graphical form for both live and archived reaction batches. Graphics screens are provided for all production, technical development and product assurance personnel. During the automatic data compression routine, approximately 60 process parameters are calculated for each reaction batch, for example, average TTC flow rate, and these can be statistically examined for trends and correlations using in-house developed routines.

Reaction data logging quickly started to help our understanding of the reaction process. The difficulties in getting operators to manually control a relatively complex process in a repeatable way immediately became apparent.

The next slide lists some of the problems in using manual control.[**]

DTL has always used a five shift system and it soon became clear that different shifts placed different interpretations on the Process Operating Instructions. Also, one of the favourite beliefs on the shop floor was that "If changing a variable made the reaction process run easier, it automatically followed that this must be good for product quality". This, of course, is very rarely true, and certainly does not hold for our process. Anybody adopting this philosophy would not be controlling his process, the process would be controlling him.

---

[*] Fig. 4

[**] Fig. 5

Shift changeovers were al so a problem. During the overlap period, when the previous shift is explaining to the next one what has happened, control parameters can often drift outside control bands. We found that by looking at a plot of a reaction batch, we could identify the shift changeover by the change in trace characteristics.

Changes in process variable settings tended to be large and infrequent, instead of being small and frequent. Consequently reaction control whilst on the whole achieving the average setting required, was most uneven.

The problems with manual control become even more acute when trying to optimise the process. Each time a new set of operating parameters is required to be tested, a temporary set of operating instructions is required. Then there is the problem of communicating these to each shift. Very often, the first few reactions under a new operating parameter regime are a mixture of the old and the new operating parameters. In practice, it has proved impossible to achieve exactly what one set out to achieve when manually controlling the reaction process.

At this stage, it was clear that improvements to the process could only be made with confidence if the variability in the measured process parameters could be significantly reduced, and it was decided to explore the possibility of introducing computer control to the reaction process.

The next slide shows the development stages required to introduce computer control.*

---

* Fig. 6

The first step was to identify which parameters could be controlled satisfactorily, and their interdependence, if applicable. A list of possible control loops was drawn up, and tram this, a shortlist was targetted. From 1983, development effort was directed at improving the performance of these control loops until in 1985, it was possible to manually enter setpoints into the associated controllers and obtain reasonable process control over some process parameters. However, temperature proved more complicated to control as this was affected by both gas firing rate and TTC flow rate and therefore could only be indirectly controlled.

During 1984 and 1985, a number of development reactions were carried out on a comprehensively instrumented reactor station to assess the potential of setpoint control. Development personnel manned the reactions round the clock, liaising with process operators whenever changes to setpoints were required. The results proved very interesting and indicated that automatic setting of setpoints by a computer should be possible.

The decision was made at the beginning of 1986 to convert one reactor station to computer control, and the relevant control loops and hardware were installed. A functional specification for the control software and hardware configuration was developed internally at DTL and circulated for comment amongst interested parties. Suitable analogue and digital output units for interfacing between the Hewlett Packard minicomputer and the individual loop controllers were identified. The interface software specification was written by DTL and developed by an outside software contractor this being the only software developed externally.

The control software was written in FORTRAN 77, a very popular scientific computer language, and this made modifications and enhancements to the program relatively easy for DTL to implement themselves.

Software development was completed in 1986, and following rigorous acceptance testing, the first "live" computer controlled reaction was carried out at the end of 1986.

The next slide shows a schematic of the computer control system.*

The overall design of the reaction computer control system is relatively straightforward. The system is designed on the principle of supervisory loop control. The setpoints of the controllers associated with a reactor station are adjusted by a host computer, in this case, the Hewlett Packard minicomputer, depending on the values of the measured process variable and the stage the reaction has reached. Valve position and control status equipment are also controlled by the computer. The computer sets the analogue and digital output units to the desired values, and these in turn output to the plant systems. The original data logging system was utilised and enhanced to provide the required level of data logging.

---

* Fig. 7

Safety considerations were of paramount importance, and none of the safety systems provided for the manually controlled process were removed or bypassed. The actual outputs tram the analogue and digital output units are monitored by the data logging system and any significant discrepancies cause alarms to sound on the plant. In the event of the computer failing, a special watchdog unit operates an alarm to inform the operators. On each reactor station, a LOCAL/REMOTE switch is provided and an operator can switch tram computer control to manual control at any time during the reaction.

During development of the computer control system, so far, I have only talked about the technical aspects of implementing computer control. The human considerations are equally important, as you ne ed to obtain the full co-operation of the workforce if you want to reap all the benefits.

The next slide shows some of the human considerations.*

Justification to the workforce for the introduction of computer control can be difficult. Computer control has often been an unfortunate expression on the shop floor, and conjures up the spectre of unemployment.

---

* Fig. 8

Fortunately, DTL were able to justify the investment in computer control on the grounds of improved reaction consistency leading to improved overall product quality. Also, at the time DTL introduced computer control, the work torce on reaction had already been cut back to the minimum safety level allowable. This meant that productivity gains were possible if production rates increased as fewer additional operators would be required.

Communication between the implementers and the operators of the system was most important. During the development cycle, operators and shift managers were consulted about the design of the interface between machine and operator and also asked to define what displays they required. Regular meetings were held to keep personnel informed as to the progress of the project.

Training was also most importante DTL place a considerable emphasis on training, as evidenced by recent success in the 1990 UK National Training Awards. All five shifts, including shift managers, were given comprehensive training in the operation of the computer control system and a special simulation program was developed in-house for this purpose. Operating instructions were developed, and these were used during the training sessions.

I am sure that the main reason for the success of the implementation of computer control was the fact that we, as a company, purposely involved the workforce at a very early stage.

During 1987 reactions were run by operators on the converted reactor station. The control program was extensively enhanced to reflect operational experience. Results exceeded expectations, and reactions carried out under computer control were much more consistent with regard to the measured process parameters, than had been the case under manual control.

What was most interesting was that initial operator scepticism had changed to enthusiasm, and they were actually asking the company when computer control would be installed on all the reactor stations.

By the end of 1987, computer control had been installed on all the reactor stations. Minimal control software changes were necessary, as this had been designed to control all the reactor stations right from the start.

DTL had now entered the computer control age.

DTL have now been running reactions under full computer control for almost three years. So, I hear you asking, what, if any, have been the benefits?

If we take the first benefit, CONTINUOUS STATISTICAL CONTROL.[*] By introducing computer control, all the process control parameters are kept within much tighter bands, and corrective action is automatically taken if a parameter exceeds a pre-programmed value. The computer is continuously monitoring instrument information and making adjustments as frequently as required. If problems occur with drifts in product quality, the reaction process can now be discounted as the direct cause as there is an assurance that the process is being controlled to known parameters. Therefore, effort can be directed at other process areas. This benefit has saved DTL many man hours of problem investigation time, and is a strong argument in itself for introducing computer control.

REPEATABILITY.[*]* The same control setpoints and control logic are applied time after time by the computer to the reaction process. The computer does not know that it is shift changeover time or that it is Monday morning. Differences in characteristics between reactor stations become more marked as the level of control improves. It is even possible to see when the fuel/air ratio on a particular gas burner needs adjusting. Diagnostic routines have been incorporated into the control program that measure the health and reliability of the instrumentation and, in some cases, can compensate for errors. One example of this is the measurement of TTC flow rate. This is measured in two ways, one directly with a flow meter and the other by calculating the average flow rate over a period, by looking at the weight of TTC fed in. The integrated TTC flow rate over the period can be compared to the actual weight of TTC fed in, and an adjustment to setpoint made.

---

* Fig. 9

* * Fig. 10

REDUCTION IN PROCESS VARIABILITY.* There are many process variables, and I do not want to comment on all of them here. In this slide, I have tabulated some of them. I have compared the characteristics of two populations of reaction batches consisting of about 200 batches each. One population is taken from 1984 when there was no computer control and the other from 1990 when there was full computer control. For process confidentiality reasons, I am unable to give values for the means of each population, but I can give the standard deviation of the means expressed as a percentage. Where the variable is a control variable, this is indicated on the right hand side of the table. As you can see, the variability of the means has been significantly reduced in all cases, even for process variables that are not being directly controlled.

CONTROLLED PROCESS DEVELOPMENT.** Incorporated into the control program is a table of about 50 parameters associated with the control of the process. Each reaction station has its own table of values. During normal production, each table is identical for all the reactor stations, and therefore, all reactions are carried out using the same control parameters and routines. However, to test different sets of process parameters, the table of values for a reactor station can be changed to permit one reaction to be carried out using non-standard conditions. Facilities ara available to obtain a representative sample from the reaction product, and the resultant quality can be assessed. All such work would of course, be covered by appropriate documentation and traceability records to cover aerospace requirements.

---

* Fig. 11

* * Fig. 12

VERSATILITY AND EASE OF MAINTENANCE.[*] The control program in use today has changed significantly from that first used in 1986. New routines have been added and logic has been modified. Changes have been relatively easy to implement, as the software has been written in FORTRAN 77, a well established high level scientific and engineering programming language. All changes and enhancements have been made in-house at DTL which, of course, has many benefits. The expertise in FORTRAN programming resides in the Process & Systems Department, which is also responsible for process development. Therefore, the people who know what is required from a process change point of view have also the skills and knowledge to make it happen. Changes can be implemented quickly, without having to instruct another company to carry out the modifications, and then probably finding, that they have not given you what you wanted.

IMPROVEMENT IN PRODUCT QUALITY.[**] In this slide I have tabulated some of the aspects of quality we measure in the finished titanium granule product. I should point out that improvement to reaction process control does not account for all of the product quality improvement as we have made improvements in other areas. However, we believe computer control on the reaction process has made the most significant improvement to quality. The finished product quality comparisons relate to the reaction batches that were the subject of the previous slide. Again, for process confidentiality reasons, I cannot give you actual values, but instead, can give improvements in mean ppm values.

As you can see from the slide the mean values for chloride, iron, oxygen and Vickers hardness between 1984 and 1990 have reduced by 300 ppm, 160 ppm, 100 ppm and 11 points respectively.

---

[*] Fig. 13

[**] Fig. 14

IMPROVEMENT IN PRODUCT QUALITY VARIABILITY.[*] This slide shows the reduction in product quality variability for the same batches shown in the previous slide.

As you can see, the standard deviation expressed as a percentage of the mean value of the populations for chloride, iron, oxygen and hardness is less for batches produced in 1990 than for those produced in 1984 indicating an improvement in product quality variability. Bear in mind that the percentages for 1990 are based on a lower mean value, and therefore, relative to 1984, there has been a very significant improvement in product quality variability.

PRODUCTIVITY.[*]* The average reaction time for 1990 reactions is about 8% less than for 1984 reactions. Also, the number of reactor stations an operator can control has increased very significantly due to the introduction of computer control.

COST SAVINGS. The average energy usage for 1990 reactions is about 10% less than for 1984 reactions. However, the largest cost saving is in the reduction of effort spent in reworking cut of specification batches. The level of rework in 1984 approached 30% at times. In 1990, the level cf rework has been less than 1%.

---

* Fig. 15

* * Fig. 16

During the last 20 or so minutes, I have tried to give you an idea of how the introduction of computer control of the reaction process was achieved, and some of the benefits we have obtained. At present, DTL is in the middle of a reaction process optimisation programme, made possible by the implementation of computer control. Already we are beginning to see further benefits.

In conclusion, I would like to thank you for your attention and hope that you found my talk interesting. I would also like to express my personal thanks to all those at DTL who made computer control of the DTL reaction process a reality and to the Company for giving permission for me to give this talk.

A.P. MORCOM'S PRESENTATION

"THE DEVELOPMENT OF COMPUTER CONTROL IN TITANIUM SPONGE GRANULEMANUFACTURE" LIST OF SLIDES

(1) SLIDE OF DTL

(2) SLIDE OF PROCESS SCHEMATIC

(3) DATA LOGGING SYSTEM SCHEMATIC

(4) INFORMATION AVAILABLE FROM REACTION DATA LOGGING SYSTEM

(5) MANUAL CONTROL PROBLEMS

(6) COMPUTER - CONTROL DEVELOPMENT STAGES

(7) REACTION COMPUTER CONTROL SYSTEM SCHEMATIC

(8) HUMAN CONSIDERATIONS

(9) CONTINUOUS STATISTICAL CONTROL

(10) REPEATABILITY

(11) REDUCTION IN PROCESS VARIABILITY

(12) CONTROLLED PROCESS DEVELOPMENT

(13) VERSATILITY AND EASE OF MAINTENANCE

(14) IMPROVEMENT IN PRODUCT QUALITY

(15) IMPROVEMENT IN PRODUCT QUALITY VARIABILITY

(16) PRODUCTIVITY AND COST SAVINGS

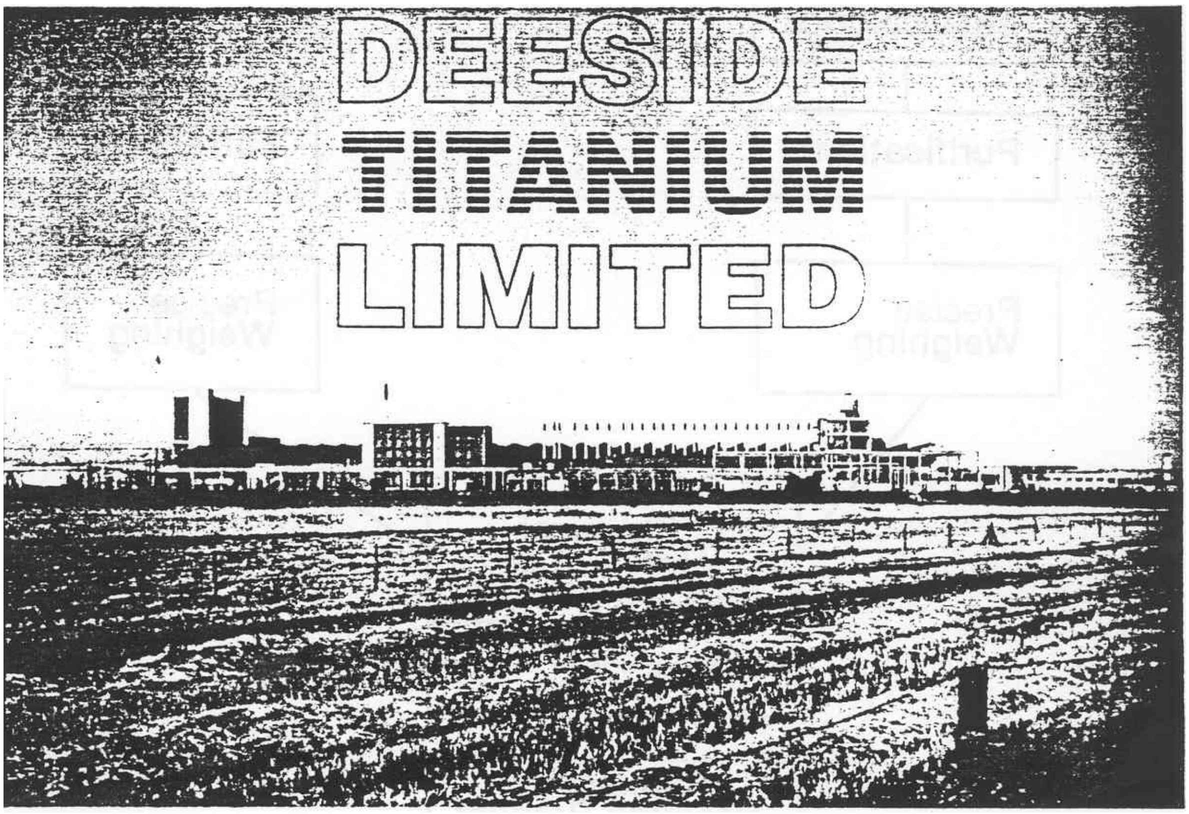


Fig. 1

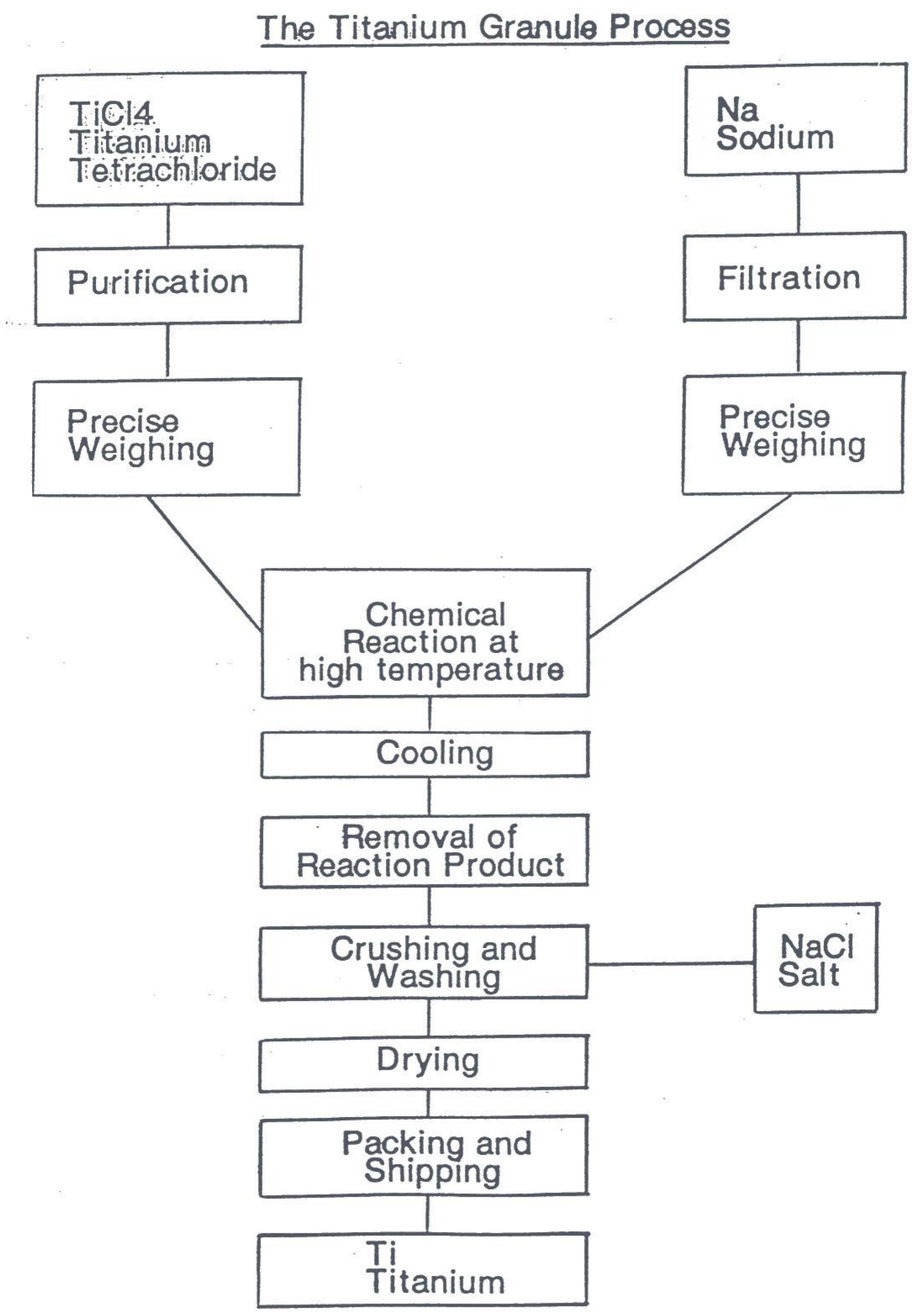

The Titanium Granule Process
TiCl4
Titanium
Tetrachloride
Purification
Precise
Weighing
Na
Sodium
Filtration
Precise
Weighing
Chemical
Reaction at
high temperature
Cooling
Removal of
Reaction Product
Crushing and
Washing
NaCl
Salt
Drying
Packing and
Shipping
Ti
Titanium

Fig. 2

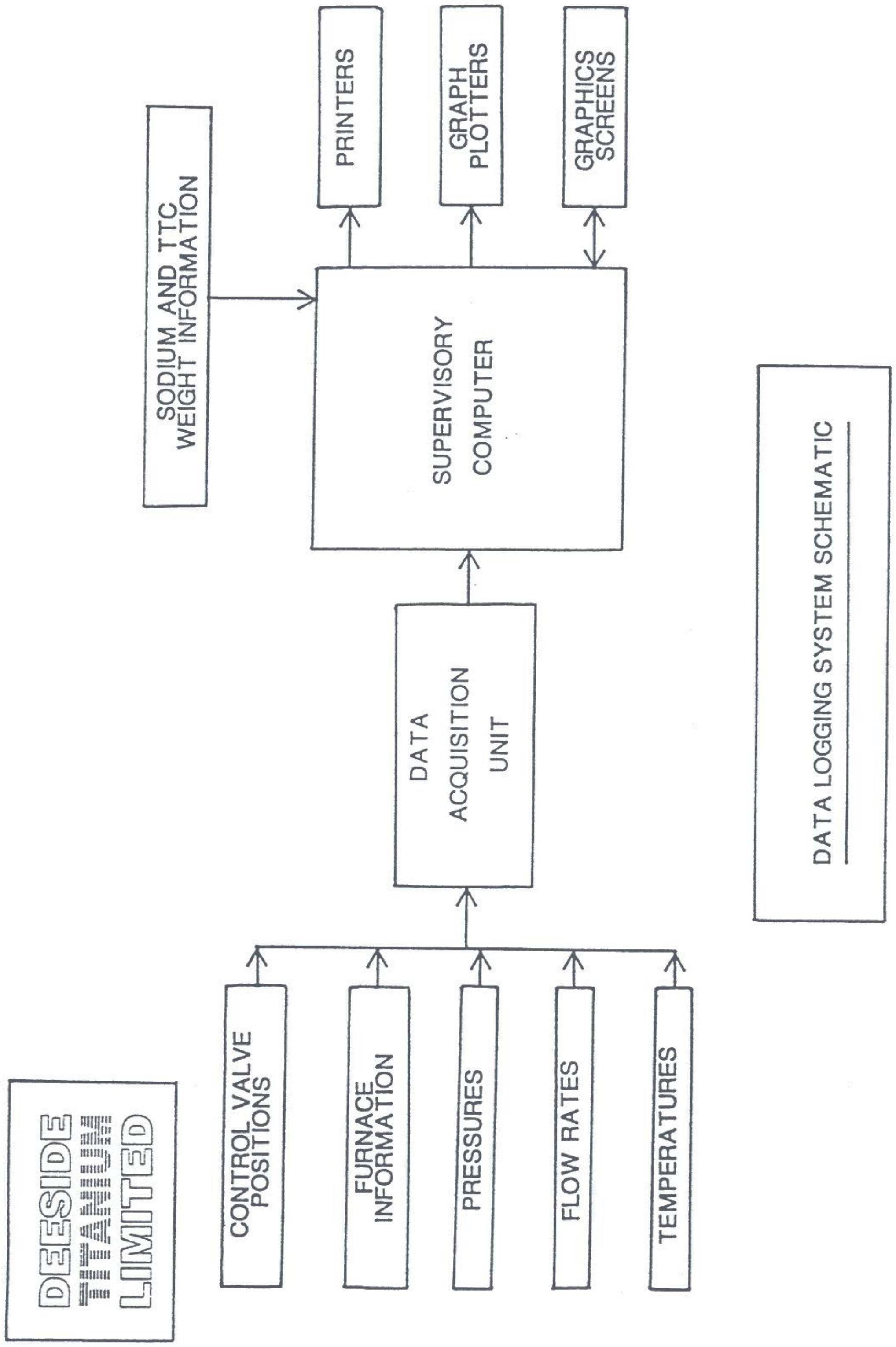

DATA LOGGING SYSTEM SCHEMATIC
SODIUM AND TTC WEIGHT INFORMATION
PRINTERS
GRAPH PLOTTERS
GRAPHICS SCREENS
SUPERVISORY COMPUTER
DATA ACQUISITION UNIT
CONTROL VALVE POSITIONS
FURNACE INFORMATION
PRESSURES
FLOW RATES
TEMPERATURES
DEESIDE TITANIUM LIMITED

Fig. 3

Fig. 4

INFORMATION AVAILABLE FROM REACTION DATA LOGGING SYSTEM

CUSUM

Exception Reports

Printout of all logged data

Bespoke statistical routines and reports

Process Variable Trends and Correlations

Historical and On-line graphical displays and plots

Compliance with Statistical Process Control criteria

Fig. 5

MANUAL CONTROL PROBLEMS

Interpretation of Instructions

Easier Equals Better

Shift Change-over

Large Infrequent Adjustments

Consistent Process Development

COMPUTER-CONTROL DEVELOPMENT STAGES

Control Loop Short-list

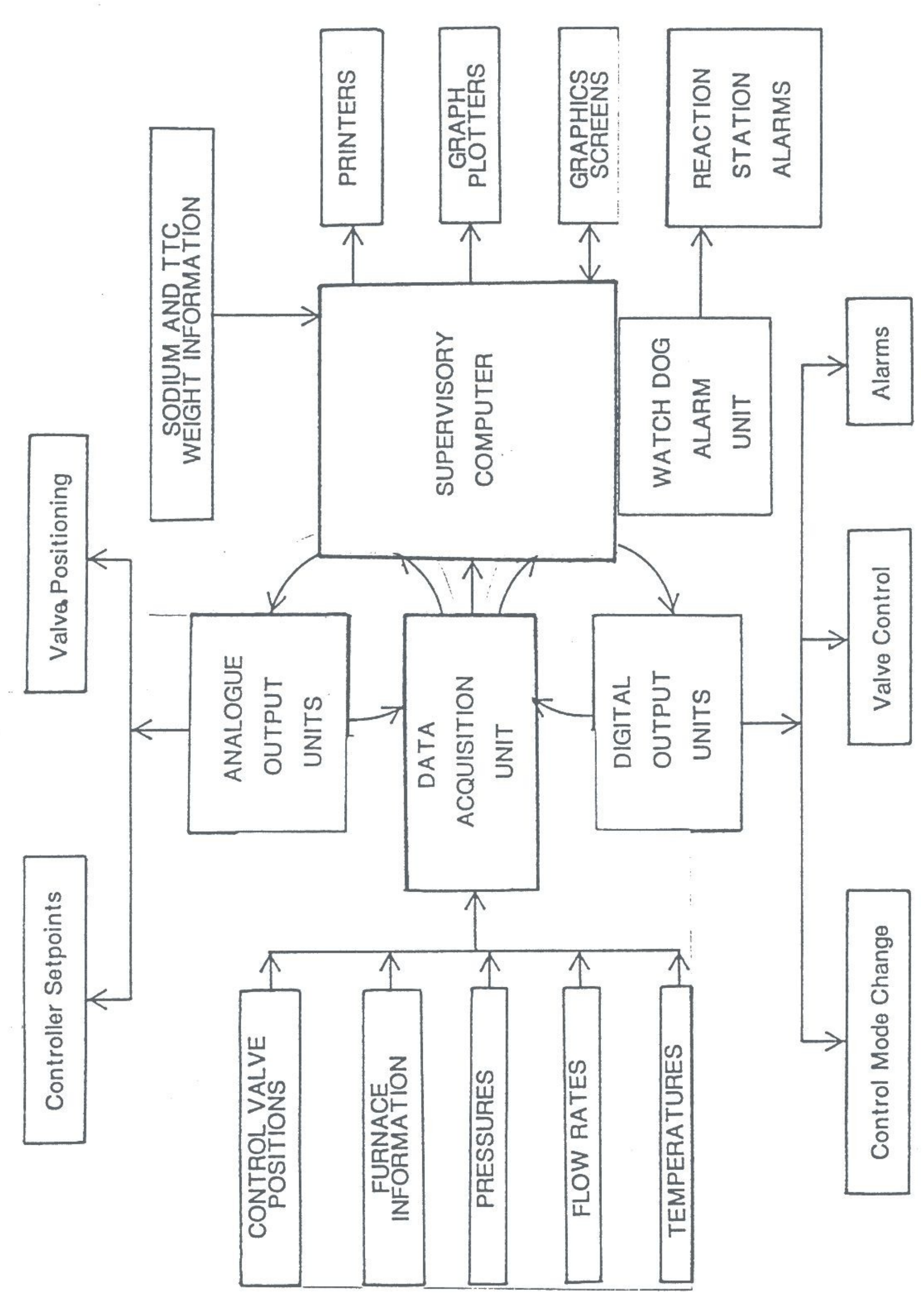
Improving Control Loop Performance

Assessment of Setpoint Control

Computer Control on One Reactor Station

(1) Functional Specification
(2) Hardware Installed
(3) Software Developed
(4) Acceptance Testing
(5) First Reaction

Fig. 6



REACTION COMPUTER CONTROL SYSTEM SCHEMATIC

Fig. 7

HUMAN CONSIDERATIONS

Unemployment

Communication

Involvement

Consultation

Training on Simulator

Fig. 8

CONTINUOUS STATISTICAL CONTROL

Parameters :- Kept within tighter bands

Assurance :- Controlling to known parameters

Saving :- Problem investigation time

Fig. 9

REPEATABILITY

Same control setpoints and logic

Highlights characteristics of Reaction Stations

Diagnostic routines can cope with errors

Fig. 10

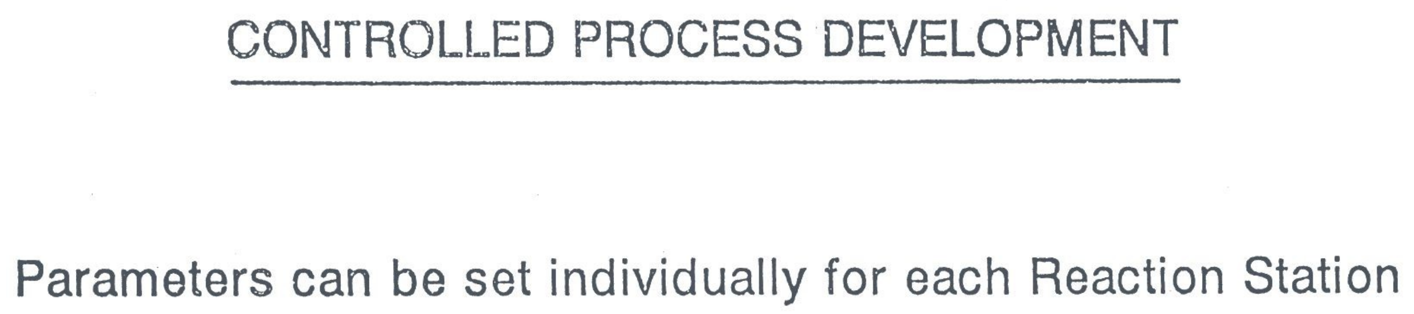
Fig. 11

REDUCTION IN PROCESS VARIABILITY

		PROCESS VARIABLE							
		TEMPERATURE	REACTION TIME				FUEL GAS USED		SINTER FACTOR
			TOTAL	START	BULK	FINISH	BULK	TOTAL	
Standard Deviation expressed as a percentage of the Population Mean	1984	0.7	6.0	9.8	6.3	17.7	28.5	16.3	48.3
	1990	0.1	2.8	7.7	2.8	6.7	14.6	11.1	14.0
Ratio of 1984 to 1990 Standard Deviation		7.0	2.1	1.3	2.3	2.6	2.0	1.5	3.5
Control Variable		YES	NO	NO	NO	NO	NO	NO	NO

TABLE SHOWING COMPARISON OF PROCESS VARIABILITY BETWEEN 1984 AND 1990 REACTIONS

Fig. 12



CONTROLLED PROCESS DEVELOPMENT

Parameters can be set individually for each Reaction Station

VERSATILITY & EASE OF MAINTENANCE

Software written in FORTRAN 77

Well established "High-level" scientific/engineering programming language

In-house programming skills

Fig. 13

IMPROVEMENT IN PRODUCT QUALITY

CHLORIDE	300
IRON	160
OXYGEN	100

Note: All figures in parts per million

VICKERS HARDNESS	11HV30

TABLE SHOWING COMPARISON OF PRODUCT QUALITY BETWEEN 1984 AND 1990 OUTPUT

Fig. 14

IMPROVEMENT IN PRODUCT QUALITY VARIABILITY

	Standard Deviation of Population as a percentage of the Mean	
	1984	1990
CHLORIDE	13.0	11.4
IRON	37.7	27.7
OXYGEN	14.4	9.6
HARDNESS	5.1	3.8

COMPARISON OF PRODUCT QUALITY VARIABILITY BETWEEN 1984 AND 1990 OUTPUT

Fig. 15

Fig. 16

PRODUCTIVITY & COST SAVINGS

Reaction times 8% shorter

One operator can control more reactions

Energy usage 10% less

Rework down from 30% to <1%