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# Impementing quality systems in a foundry

**Bosch, Cyril Henry**

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TITLE

# IMPLEMENTING QUALITY SYSTEMS IN A FOUNDRY

by

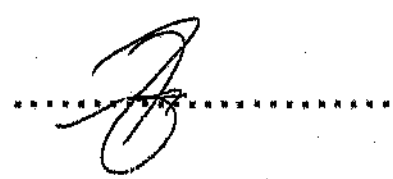
Cyril Henry Bosch

A project report submitted to the Faculty of Engineering, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Master of Science in Engineering.

Johannesburg, 1991

# DECLARATION

I declare that this project report is my own, unaided work. It is being submitted for the Degree of Master of Science in Engineering in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.



.....31..... day of .October..... 1991

physical properties monitored. Hardness is tested by means of a Brinell Hardness tester. A carbide ball of known diameter is pressed under a control load onto the test surface causing a small indentation. The diameter of this impression is measured by means of a calibrated scope. A look up table gives a correlation between the impression diameter and the brinell hardness. A more accurate method for measuring the diameter is using a magnified shadow graph and digital calipers. The latter equipment is only available at Auto Industrial.

## 7.3 DISC BRAKE CASE STUDY

Specifications for the AIF 852 Disc Brake, (See Photograph 18) which is made from a special high carbon steel, calls for a brinell hardness of between 160 and 200. The customer requires 100% hardness testing for the first three production batches of at least a quantity of 500 per batch.

A trial batch of approximately 250 discs were run and subjected to 100% hardness testing using the shadow graph method.

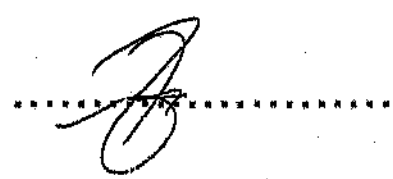
Standard statistical analysis of the results are shown in Fig. 7.1, 7.2 and Table 7.1 over leaf

Of the 246 actual discs, 4 were completely out of specification - two too hard and two too soft.

The average hardness of measured was 185.2 with a reasonable normal distribution. One important fact is

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# ABSTRACT

The purpose of this project was to introduce an effective Quality Control Systems into a newly established foundry. The parent company expressed concern about the poor quality of locally produced castings and decided to invest in it's own foundry. As the company exclusively produces components for the motor manufacturing industry it was of paramount importance that the foundry is equipped and run in accordance to the high manufacturing standards set by the major motor manufactures. As the Auto Industrial Group is committed to a Total Quality Control programme in line with the high-tech motor manufacturers it is obvious that the foundry follow suite. The strategy adopted was to base a Quality Management System along the lines of SABS 0157 and to expand it to ensure that all the Quality Requirements of the customers are accommodated

# DEDICATION

IN MEMORY OF M.' PARENTS

HENRY and GRACE BOSCH

# ACKNOWLEDGMENTS

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# CONTENTS

Page

TITLE .....i

DECLARATION .....ii

ABSTRACT .....iii

DEDICATION .....iv

ACKNOWLEDGEMENTS .....v

CONTENTS .....vi

LIST OF FIGURES .....ix

LIST OF TABLES .....x

1 INTRODUCTION . .....1

1.1 Problem Statement .....1

1.2 Overview of the Situation .....1

1.3 Literary Survey .....3

1.4 Theoretical Solution .....4

1.5 Proposed Solution .....5

1.6 The Basic Process .....6

2 SABS 0157 Part 2 .....9

2.1 The Need .....9

2.2 Fundamental Requirements of SABS 0157....9

2.3 Overview of SABS 0157 Part 2 .....10

3 QUALITY SYSTEMS .....14

3.1 View point of Quality Systems .....14
3.2 Q-101 .....18
3.3 QSK-01 .....20
3.4 Nissan's SQA & Supplier Develop. Assess..22
3.5 VW - Supplier Quality Development (SQD) .28
3.6 Are SQA Systems Necessary? .....25
4 FAILURE MODE & EFFECT ANALYSIS
4.1 Introduction to FMEA .....26
4.2 FMEA Team .....27
4.3 Sequence of Operations .....28
4.4 Analysis of Failures .....29
4.5 Current and Improved Risk Factor .....32
4.6 Safety Critical Components .....34
4.7 Conclusion .....35
5 INFRASTRUCTURE OF THE QUALITY SYSTEM .....37
5.1 Provision of Resources .....37
5.2 Quality Policy .....38
5.3 Objectives .....40
5.4 Standard Operating Procedures .....41
5.5 Works Instructions .....42
6 DESIGN OF EXPERIMENT .....45
6.1 Basic Principal of a Green Sand Plant ...45
6.2 Purpose and Methodology .....49
6.3 Results and Analysis .....52
6.4 Effects and Interactions .....56

7 CAPABILITY STUDY .....58
7.1 Definition .....58
7.2 Metal Hardness Measurement .....58
7.3 Disc Brake Case Study .....59
7.4 Recommendations .....61
7.5 Second Run .....62
7.6 Review of the Problem Situation .....62
7.7 Third Run .....64
8 PROCESS CONTROL .....67
8.1 Purpose .....67
8.2 Metallurgical Control .....69
8.3 Sand Plant Control .....71
8.4 Production Process Control .....73
9 CONCLUSION .....76
9.1 SABS 0157 .....76
9.2 Quality Audits .....77
9.3 Design of Experiment .. .....78
9.4 Capability Study .....79
9.5 Process Control .....80
9.6 Lessons Learnt .....80
9.7 Future Improvement .....82
10 APPENDIX A .....83
11 REFERENCES .....95
12 BIBLIOGRAPHY .....97

# LIST OF FIGURES

Page

fig 1.1 Quality Perception .....2

fig 1.2 Foundry Flow Chart .....8

fig 3.1 Naive Picture of Quality Systems .....14

fig 3.2 Reductionist Approach to Problem Solving .15

fig 3.3 Rich Picture of Quality Systems .....17

fig 4.1 FMEA Form .....30

fig 5.1 Quality Structure .....38

fig 5.2 Process Specification sheet .....44

fig 6.1 Moulding Sand Preparation .....45

fig 6.2 Green Sand Cycle .....46

fig 6.3 Experimental Parameters .....51

fig 7.1 Histobars .....60

fig 7.2 X Chart - 3 Sigma Limits .....60

fig 8.1 Variation in Distribution .....67

fig 8.2 Metal pour Temperature Control .....70

fig 8.3 Green Sand Compactibility Control Chart ..72a

fig 8.6 p-Chart for Percentage Defective .....75

# LIST OF TABLES

table 6.1 Yates Method .....50
table 6.2 Experiment Results .....53
table 6.3 Method of Analysis .....54
table 6.4 Effects and Interactions .....55
table 6.5 Effect and Interactions Summary .....56
table 7.1 Statistical Analysis .....60
table 8.1 p-Chart for %Scrap Control .....74

# 1 INTRODUCTION

## 1.1 PROBLEM STATEMENT

To design an optimum quality system using a hard systems engineering approach and together with all mandatory quality controls systems required by the customers, produce casting for the motor industry at a maximum profit contribution.

## 1.2 OVERVIEW OF THE SITUATION

It seems illogical that in a depressed economy and in a saturated market a new automatic high production foundry should be commissioned. Yet the justification is simple - QUALITY.

The major activity of the Auto Industrial group is the machining of motor components. Defective component castings account for the highest loss of contribution as at this late stage when the defect is detected it is too late and all the manufacturing effort expended is lost.

In the light of ever increasing competitiveness, both from local manufacturers and importers, it is becoming more desirable to produce motor components with greater profit contribution. Apart from design optimization, over which the component manufacturer has

little control, it is believed that the greatest results can be achieved in optimising all round quality. High priority must be given to the stringent quality requirements of the various motor car manufactures. Optimized solutions must be able to be simulated so that production results can be fed back and compared to the problem model. This allows for constant fine tuning and ensures perpetuation.

Typically quality is measured during the manufacturing process as "conformance to specifications". Motor manufacturers have developed systems for establishing quality standards in both manufacturing and supply or components and raw materials - as shown in fig. 1.1. Yet the customer, in detecting a failure reports these as being "unfit for use".

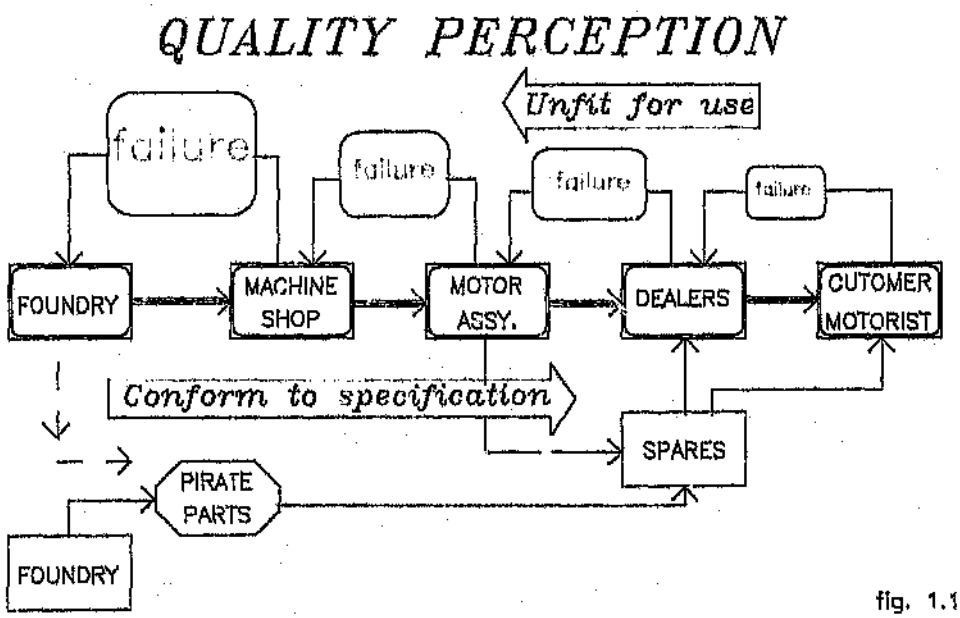



fig. 1.1

## 1.3 LITERARY SURVEY

Frequently articles concerning Quality and related Statistical topics appear in Engineering Journals. Of particular interest to Quality in manufacturing are contributions by Messrs. John S Lawson, Douglas C Montgomery, J Clifton Young et al, G E P Box, A Pratt & X Tort, K S Krishnmoorthi. Common topics covered include statistical methods, experimental design and examples of quality in industry.

Requirements, quality standards and quality audits of the various motor manufactures will be taken from their respective Quality Journals, i.e SAMCOR statistical procedures. SABS 0157 part 2 will form the background to the quality procedures and instructions.

These authors provide a relatively wide theoretical and practical spectrum to generalised quality topics. Most of the work covered can be adapted and programmed into a PC using available spreadsheets, databases, and program languages.

The main sources of quality theory will be taken from "What is Total Quality Control?" by Kaoru Ishikawa and "Statistical Quality Control by Grant & Levenworth. Statistical concepts to be sourced from "Probability & Statistics for Engineers and Scientists" by Walpole & Myers.

To supplement this relevant sections from Operation

Management by Schonburger & Knod, Production Systems Planning, Analysis & Control by Riggs and Automation,Production, Systems & Computer Integrated Manufacturing by Groover.

Systems Engineering approach to problem solving will be referenced from Wilson and Chechland.

## 1.4 THEORETICAL SOLUTION

A hard System Engineering type approach to be adopted in problem solving. Andrew Sage (4) defines this type of approach as - "Systems Engineering is an appropiate combination of the Mathematical theory systems and behavioral theory in a useful setting appropiate for the resolution of real world problems."

Having developed a possible model solution, using the basic Wilson methodology, a simulated model is to be developed so that further problems can be made apparent. Applying statistical techniques to production data collected from the sand plant in a designed experiment, effects and interactions are to be investigated. Yet there still lingers an air of mystique concerning the characteristics and these will hopefully be explained by the examination of the interactions of the major variables

At the outset, systems for both frequent and

periodic measuring of Shop Loading, Production Output, Process Quality, Scrap, Rework and Process Control must be set up.

## 1.5 PROPOSED SOLUTION

Manufacturing philosophies and manufacturing quality strategies need to be formalised as an initial step. This will possibly define manufacturing quality systems which are to be used i.e. SABS 0157 part 2, Ford's Q101, BMW's QSK-01 Quality Standards, FMEA, etc.

The most fundamental quality issues of process control, in particular the Green Sand plant, need to be investigated using Statistical Methods.

Systems for monitoring the production output levels and process control have been implemented and these include:-

* Furnace loading and melt analysis
* Pouring temperature and delivered quantity
* Mould production and machinery status
* Core production and machinery status
* Green sand production and machinery status
* Hourly monitoring sand physical propeties
* Twice daily sand makeup checks
* Raw material receiving inspection
* Defect analysis

The flow diagram, fig 1.2, at the end of this

chapter shows the inspection procedures in relation to the product flow. At each of these points exists a data recording / capture system. Analysis of this data will be used in determining the process capability limits.

The results of these Investigations will form the basis of "Work Instructions" and "Operating Procedures" for establishing Quality Standards and Quality Procedures which are dictated by the customers.

The object of the project is, therefore, to get the process into control and implement control means which will ensure that the overall process manufacturing systems will remain in control.

## 1.6 THE BASIC PROCESS

The process starts with the buying of scrap metal. As the output steel quality is very tightly controlled by means of chemical and metallurgical specifications, much effort must be expended in grading this "raw material". Different grades of steel and cast iron are separated and sorted according to spectro chemical analysis.

Melting furnaces are charged with carefully weighed ingredients according to the melt schedule. Before delivering molten metal to the holding furnace or to

the line test samples are taken to ensure conformance to specifications.

The sand plant prepares the "green sand" (not because of it's colour but because it is wet) mix for the automatic moulding line. Samples of sand from each batch are subjected to a compatibility test to ensure consistency. Samples are also taken every hour and subjected to more detailed physical tests like tensile, crush, shear strengths and moisture content. Twice daily sand makeup tests like the percentages live clay, dead clay, fines, and the loss of ignition which gives the coal dust content are monitored.

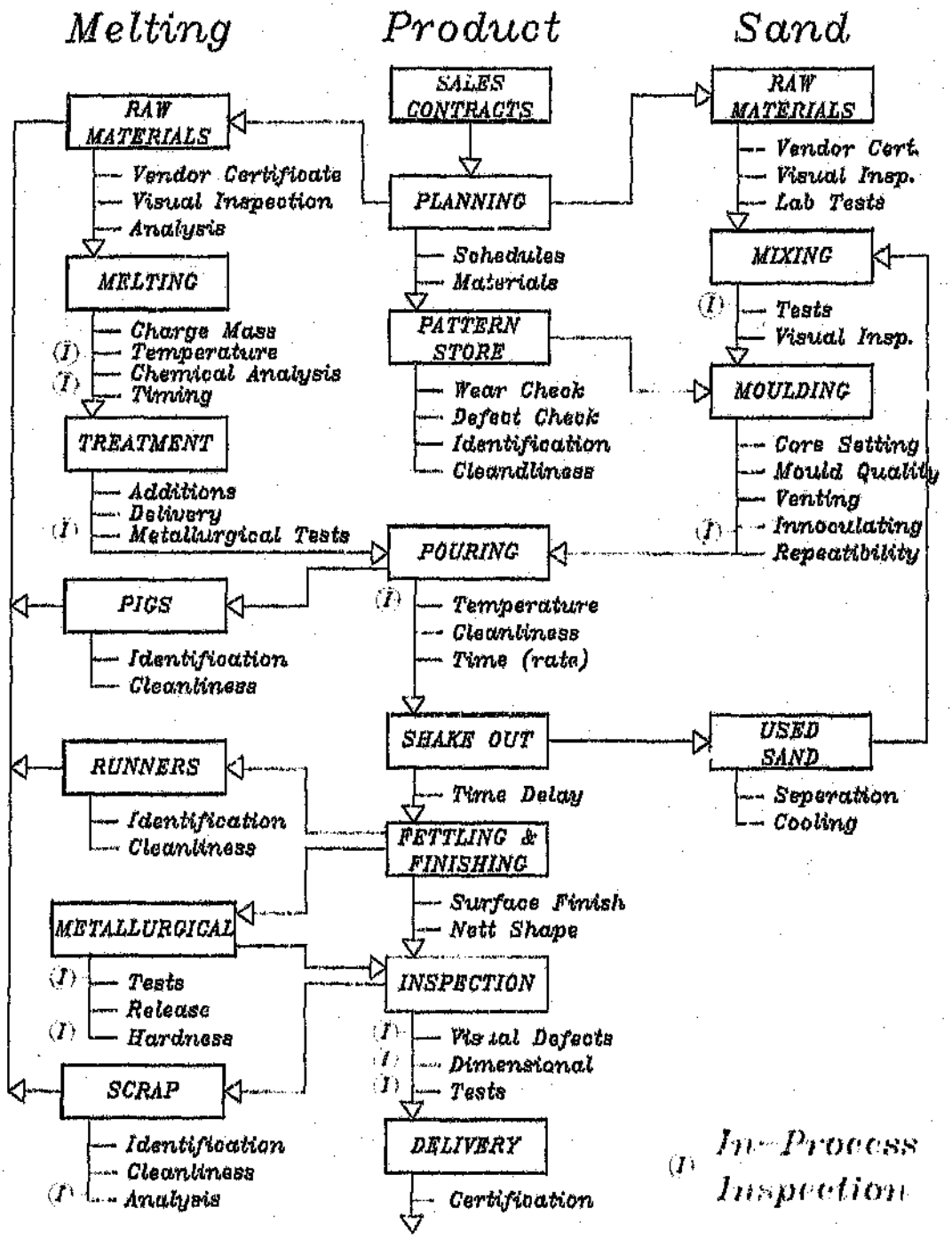
After forming the moulds in two half sections, the core (if required) is inserted together with mould innoculant and strainer. The mould is then closed and sent to the pouring line. Metal pouring temperature is critical in the casting process and therefore carefully monitored. After going through the cooling lanes the mould is broken and the casting removed on a vibrating conveyor. This separates the sand from the metal and is returned to the sand plant by conveyor.

Photographs depicting these manufacturing processes are appended in appendix A.

A flow diagram giving details of the manufacturing operations and the process sequence follows over the page.

fig 1.2

# FOUNDRY FLOW CHART



# 2 SABS 0157 Part 2

## 2.1 THE NEED

As manufacturing processes become more and more complex the need for rationalisation and standardisation becomes more apparent. Mass production methods call for consistency in materials and processes to reduce the amount of custom "fitting" in assemblies. Production managers soon realize the advantages of "right first time" manufacturing philosophy using methods focused on simplifying operations and "fool proofing".

The SABS first published the "National Code of Practice for Quality Management Systems, SABS 0157 parts I to III" in 1979. This was much in line with current international developments. These Standards have since been rationalised into the ISO 9000 series of Quality Assurance standards, although SABS has retained the name SABS 0157.

## 2.2 FUNDAMENTAL REQUIREMENTS FOR SABS

All quality systems need certain fundamental requirements (3) to be met in order to be successful. Without them the system will be doomed to certain failure. Quality systems, like SABS, are not just lip service exercises which will satisfy quality audits and

assessors. These provide the infrastructure for bonding together all quality efforts into a practical and useful Quality Management System.

These fundamental requirements are defined as follows:-

* Awareness - The concept of quality management and quality systems must be understood by the Quality Management Team.

* Commitment - The Quality Management Team must be totally committed to the philosophy of Quality Management.

* Organization - The organization structure must be clearly defined and the Quality Management Team concerned with the implementing and monitoring product defects.

* Provision of Resources - Top management must make available the necessary funds to effectively implement Quality Assurance Systems.

## 2.8 OVERVIEW OF SABS 0157 PART 2

SABS 0157 is divided into 5 parts.

Part 0 - Quality Management and Quality Assurance Standards - Guidelines for selection and use.

Part I - Quality Systems - model for Quality in Design - Development, Production, Installation and Servicing.

Part II - Quality System - Model for Quality Assurance

in Production and Installation.

Part III - Quality Systems - Model for Quality Assurance in Final Inspection and Test.

Part IV - Quality Management and Quality System Elements - Guidelines.

Part 2 is the accepted norm for the manufacturing industry.

This is based on ISO 9002 Quality Systems. Specifically it is for use to ensure conformance to specified requirements by the supplier during production. This is achieved by the compilation of a Quality Manual. In this manual the following minimum Quality Systems must be defined and documented :-

* Management responsibility
* Quality system
* Contract review
* Document control
* Purchasing
* Purchaser supplied product
* Product identification and traceability
* Process control
* Inspection and testing
* Inspection, measuring and test equipment
* Inspection and test results
* Control of nonconforming product
* Corrective action
* Handling, storage, packing and delivery

* Quality records
* Internal quality audits
* Training
* Statistical Techniques.

The structure chosen for this manual is to take each of the above mentioned topics as an Operating Procedure. Each operating procedure is then detailed with Work Instruction or instructions to supplement the Operating Procedures. This helps to logically structure the manual and reduces the need to repeat many common standing instructions. Operating Procedures and Work Instructions are systematically numbered and indexed for easy reference.

Included in the system is a numbering system for all documents mentioned in both the Operating Systems and the Works Instructions. This is required to standardise, and possibly minimise the amount of forms to be used in the system.

Traceability for procedures and instructions for every form must exist. This implies that all quality related information i.e. material analyses, hardness tests, production records, etc., must be able to be traced for every single component manufactured. These records are generally expected to be kept for 8 years - although "safety critical" components must be kept for 10 years.

However, BABS does not address all the necessary

issues for the manufacturing of automotive components to customer specifications. It is, therefore, necessary to supplement it with additional systems so that issues of Q-101, VW Quality Systems, BMW Quality Standards, Mercedes Bendz , etc., can be addressed within a single Quality Assurance System.

# 3 QUALITY SYSTEMS

## 3.1 VIEW POINT OF QUALITY

Normally quality is viewed as shown in the diagram (fig.3.1) and represents the more traditional view point of a Quality System.

*NAIVE PICTURE OF QUALITY SYSTEMS*

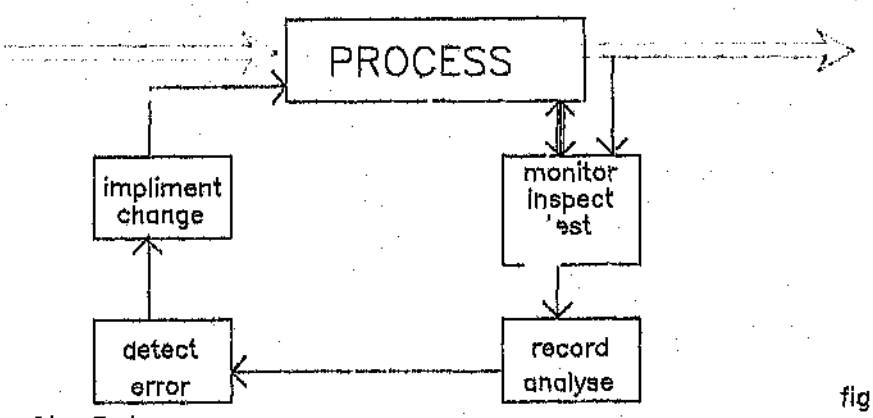



fig. 3.1

fig 3.1

This system monitors the output of the process. When nonconformance is detected a corrective action is applied and the output is again monitored to ensure that the corrective action has had the desired effect. This sort of reductionist hit and miss approach to problem solving is depicted in fig 3.2

The problem with this sort of problem solving technique is that only a very limited view of the symptoms are identified and the impact of the solution is not viewed in conjunction with all the other

interactive systems. Expressed in terms of Murphy's Laws "new solutions breed new problems"

The Systems Engineering approach is to adopt a more holistic view of both the problem and the solution and the relationship between them.

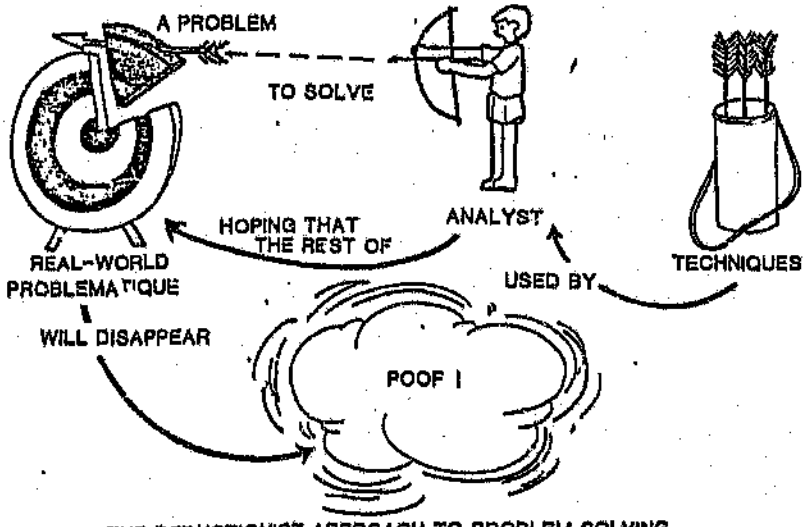



fig 3.2

The first step in System Engineering is to change the "naive" picture into a "rich" picture by a wider view of the problem situation. This aids the definition of the whole problematique so that a conceptual model can be developed. A technique for achieving this is C-A-P-T-O-W-E analysis, as explained by Wilson (5).

Using this approach to Quality Management Systems yielded this analysis:

Customer - The end user, in this case the motorist

Actors - Quality Assurance department of both the manufacturer and the motor assembly plant

Performance - Quality standards as defined by SABS and the various motor manufacturers

Transformation - Converting reclaimed steel into high quality automotive components efficiently

Weltanschauung - Motor manufacturers perception of the Quality Standards of the component manufactures

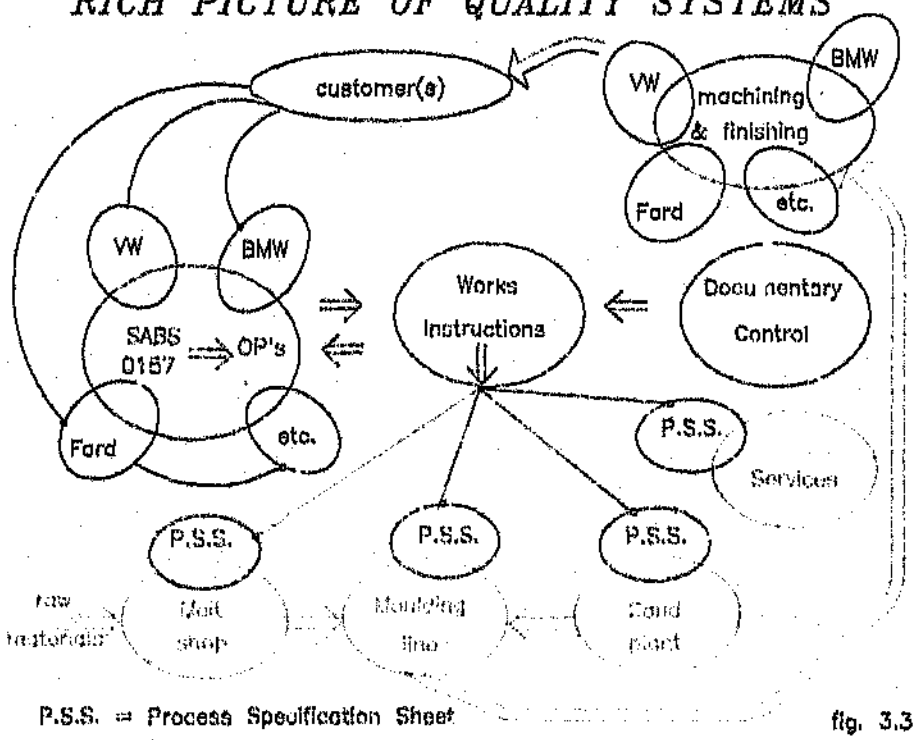
Ownership - Component manufacturer's manufacturing capability

Environment - Restrained to the motor manufacturer's specifications and supply contractual agreement

And this leads to the following definition of the problematique:-

The component manufacturers ability to produce automotive components to the specifications required, in the agreed quantity, to the delivery schedule and at a price which will allow for fair mutual profits.

*RICH PICTURE OF QUALITY SYSTEMS*




P.S.S. = Process Specification Sheet

fig. 3.3

Significant in the above diagram is the apparent complexity of the interactions of all the quality sub systems. The motor manufactures i.e. VW, BMW, Ford, etc., each have their own specific requirements imposed on the component manufacturer. The system suggests that all of these plus requirements of SABS are transformed into Operating Procedures. These Operating Procedures are supported by detailed Works Instructions which together with Process Specification Sheets and Documentary Control define the exact parameters for the various manufacturing processes.

Castings , the output of AIF, are the raw materials

used in the next phase of conversion. Again the same vendor specifications are imposed. This, no doubt, leads to a very tight bond between the foundry and the machining / finishing procedures. It is also this link which is the justification for AIF's existence - simply because other foundries which Auto Industrial used could not ship the desired quality.

This is the reason why "machining / finishing ... r on the diagram - all part of the same group.

3.2 Q-101

The emphasis of SABS 0157 is on quality management systems and although the need for statistical control is addressed, it is somewhat vague. Ford Quality Control Specification Q-101 is a quality system used by Ford on it's suppliers (6). The function of this system is to ensure that suppliers are using effective statistical methods to produce components to within the the minimum laid down standards. This is in itself a quality restriction in as much that compliance is to minimum standards - ensuring that only barely a minimum will be achieved, but this is further qualified in that the system does encourage ongoing quality improvement.

This basic format of statistical quality assurance is used by most other motor manufacturers.

In essence the goals of Q-101 are as follows:-

* Produce products whose quality is unsurpassed by major competitors
* Only products which fully comply with engineering specifications may be shipped to Ford
* Requirements are met efficiently - both from cost and timing point of view. Consistent quality nullifies the need for after-the-fact inspecting to find defects.
* Consistency in quality can only be achieved in a process which is inherently capable of consistency.
* Process performance depends on both the combined effects of machine capability and process control.
* All processes must be conducted within their process capability

This ultimately leads to the conclusion that this system is concerned with the fact that the process capability must be quantified and that the ongoing production must be kept within the defined process capability limits. This implies that the process must be capable of performing within the limits at the outset. Although this sounds very fundamental it has some profound ramifications in the foundry industry. Unlike machining operations which are easily defined and where the capability is readily measurable, the foundry process is largely dependent on operator judgement. Even in the most sophisticated foundries,

automation is limited to relatively few processes. Is it, therefore, fair that the same quality control systems should be applied? Determining the process capability of many operations is in fact determining the capability of the process operator!

## 3.3 QSK-01

Another example of vendor quality system is QSK-01, supplier quality assurance system assessment questionnaire as used by BMW.

The function of this is to assess the quality prowess of the component supplier. In order to determine the "degree of attainment" twenty quality aspects are addressed. Namely:-

| | Score |
|---|---|
| 1) Organisation - QA System - Job Descriptions etc. | (90) |
| 2) Planning - Project Planning - Procurement Plan | (60) |
| 3) Document Control - Defined System | (50) |
| 4) Production Equipment Control-Capability Studies | (50) |
| 5) Production Procedures-Written Work Instructions | (50) |
| 6) QC Procedures - Methods - Inspection - Archives | (50) |
| 7) Product Requirement-Guarantee Acceptable Quality | (80) |
| 8) Laboratory and Inspection Equipment - Adequate | (45) |
| 9) Sub-Supplier Q.Assurance-Supplier Assessment | (60) |

10)Process Parameters - Maintenance (30)

11)In Process Inspection - Regular Checks (30)

12)Final Inspection - Conformance to Specification (30)

13)Process Control - Statistical Methods (30)

14)Non Conforming Product - Segregate (30)

15)Inspection and Test Status - Identified (30)

16)Material Handling - FIFO - Correct Methods (30)

17)Training Programme - Quality Improvement (30)

18)Documentation and Records - "D" Parts 10 Years (55)

19)Corrective Action Procedures-Written Instruction(30)

20)BMW Access to Suppliers - Adequate (80)

TOTAL 855

The assessment of quality is as follows:-

| | | |
|---|---|---|
| 825 - 855 | A1 | Meets the requirements |
| 755 - 820 | A2 | Predominantly meets the requirements |
| 645 - 750 | B1 | Meets most of the requirements |
| 530 - 640 | B2 | Only meets requirements conditionally |
| (530 | C | Does not meet the requirements |

Therefore, in order to supply BMW a minimum of a B2 rating is required.

The system is designed to structure an improvement programme for "weak" quality areas. A Gantt chart type programme is drawn up for each topic for the next twelve months so that future audits can be measured to ensure quality progress.

## 3.4 NISSAN'S SQA & SUPPLIER DEVELOPMENT ASSESSMENTS

Nissan's Supplier Quality Assurance (SQA) is based directly on SABS 0157. The purpose is to establish procedure guidelines to ensure that all products and services delivered to Nissan meet all the specifications.

Nissan will audit its suppliers, usually annually, to ensure total conformance. Areas deemed as non-compliant will require a documented corrective action plan which will be mutually agreed upon.

Assessment guide is directly linked to SABS requirements. On completion of the quality audit, suppliers will be rated with A, B, C, or D grade.

A = Fully assured to manufacture components.

B = Assured with items of minor non-conformance. Minor non-conformances would be a non-conformance which will not affect the product in any way. Normally this would be a document type of non-conformance.

C = Conditionally assured. This condition will be for a limited period only and followed up by a further assessment.

D = Disassured. May not supply components.

A full report detailing all non-conformances as either serious or minor together with recommendations

is submitted to the supplier.

## 9.5 VW - SUPPLIER QUALITY DEVELOPMENT (SQD)

Although this system requires a quality manual based on SABS 0157, there no direct connection between SQD and SABS. In essence the audit system is divided as follows:-

Part 1 - Organisational Requirements

| | Points |
|---|---|
| Organisation | 340 |
| Q.A. General | 30 |
| Quality Planning | 192 |
| In-Process Q.A. | 88 |
| Q.A. Principles | 36 |
| Production | 54 |
| TLD - Documentation | 142 |

Part 2 - Requirements according to Production Technologies

| | |
|---|---|
| Goods Receiving/Stores | 56 |
| Assuring Quality Supply | 146 |
| Inspection of Finished Goods | 362 |
| Final Inspection Product Audit | 290 |
| Storage Conditions - Despatch | 72 |
| Reliability Testing | -- |

Maintenance of Insp/Prod Equipment 40

Production Conditions and Monitoring

1) Sand Mix 174

2) Core/Mould 174

3) Melt Furnace 174

4) Casting/Moulding 174

5) Fettling/Finishing 174

The results of these items determines the overall grade as follows:

| GRADE | QUALITY CAPABILITY | DESCRIPTION | CONSEQUENCES |
|---|---|---|---|
| A | 90 - 100% | Quality Capable | None |
| B | 75 - 89% | Conditional Quality Capable | Improvement Plan |
| C | 0 - 74% | Not Quality Capable | Immediate Action Plan |

The outstanding feature of this audit system is that a high degree of significance is given to the actual manufacturing process. This makes it a more personal system and more user friendly system to both VW and the supplier.

## 3.6 ARE SUPPLIER QUALITY ASSURANCE SYSTEMS NECESSARY?

It is indeed a pity that in addition to SABS each motor manufacturer polices its own supplier quality assurance system. The question is why and at what cost?

Seemingly, motor manufactures do not believe that the quality standards set by SABS are sufficiently high or that SABS are capable of implementing the requirements of the motor industry. There are examples of foundries which have SABS approval yet do not meet the quality standards of most motor manufactures.

If there are eight motor manufactures which each employ an average of five supplier quality assurance engineers at say a cost of R100 000 it means that there is a direct expense of R4m plus travelling, accommodation, etc. If the supplier who supplies to all the motor manufactures is audited only once a year at 3 days per audit it means a loss of 24 working days to the supplier quality department plus moderate interruptions to production management. For 500 suppliers this amounts to 12 000 lost days.

I do nr. believe that this either justifiable or necessary. I think that this problem should be addressed by both SABS and the Motor Manufactures Federation to set supply standards for the motor industry as a whole.

# 4 FAILURE MODE & EFFECT ANALYSIS

## 4.1 INTRODUCTION TO FMEA

A completely different approach to Quality Systems is that taken in Failure Mode and Effect Analysis (FMEA). The object of this analysis is to numerically evaluate the result of the failure or anticipated failure of the component or sub-part of a component. Component failures can be clearly classified into either a failure as a result of poor design or a failure as a result of poor manufacturing techniques. The same basic principles are applied to component design as to the production processes in order to attempt to evaluate the result of a failure. Component FMEA is usually only used by the design engineering department, while the latter is more commonly used by production engineering department.

Component failures will vary in seriousness from minor annoyance or inconvenience to, at the other extreme, major hazard which effects the safety of people, resulting in the loss of life or limb. The latter are classified as "Safety Critical" and each manufacturer has a method of identifying the specific attribute which accounts for the criticality. These components have to be handled with extreme care. Non

conformance to specifications are not tolerated at all and any improvements, alterations (i.e. refurbished or replaced tooling) or "modifications" will have to be vetted by the overseas principal manufactures.

As no component development takes place at the foundry and all components are made to principal manufactures drawings and specifications, FMEA's will be limited to Process and Manufacturing only.

The result of design FMEAs are safety critical specifications on components. As a typical example on a disk brake casting drawing the following safety critical items appear on a Volkswagen drawing - "100% Crack Free" and "Defects which adversely affect the strength of this component are not permitted". These very broad based specifications effectively means that no deviations in specifications can be made and also that process FMEAs must ensure that defects identified in the manufacturing process will not effect the component safety and reliability in any way.

## 4.2 FMEA TEAM

Choosing the team is important. The object is to get as broad as possible spectrum which must include, at least, all the manufacturing disciplines while not making the team too big so that decision making becomes difficult. The ideal number is 5 people.

In putting together the team the following must also be taken into account:-

*Representatives from major disciplines

*Team leader and secretary

*Not too many "strong" personalities

*Team members must be trained in FMEA

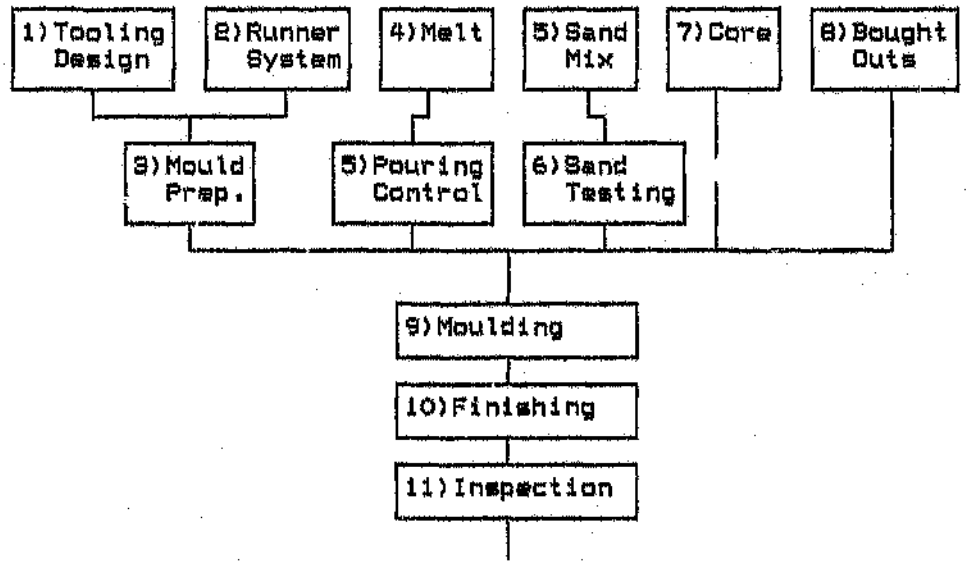
*Time limit - i.e. avoid interruptions

*Time table for review meetings

*Pre-meeting preparations organised

*Suitable venue

## 4.3 SEQUENCE OF OPERATIONS




The surest method of ensuring that all operations are included in the FMEA is to follow the manufacturing operations, as shown above. An example of a FMEA form

is shown in fig. 4.1, which is an A3 size form for ease of use. These operation are then filled in on the first column labeled "Operation Sequence."

## 4.4 ANALYSIS OF FAILURES

The object at this stage is to list all the possible failures which could take place with each of the listed operations. For example examine the forth operation "Melt". Ask the question "What will happen if the melt procedure goes wrong?". The answer to this question is the potential actual failure. It is necessary to be very pessimistic. This implies the examination of the worst possible scenarios. The team must be encouraged to divulge all the process short comings and not to hide system failures.

Examples of actual failure modes are described below. The question to be considered to stress the importance of potential failure is "Could it?" as opposed to "Will it?". Typical failure modes are:

| | | |
|---|---|---|
| Oversize | Cracked | Pourous |
| Undersize | Open | Misaligned |
| Rough | Shorted | Out-of-balance |
| Eccentric | Leaking | Deformed |
| Missassembled | Damaged | Omitted |

Meetings

| Potential Failure (Actual) | Potential Consequences for the Customer (Effect) | Potential Reasons for the Failure (Cause) | O | Current Status: Existing Control Measures | Severity | Occurrence | Detection | Risk Priority Factor | Recommend Corrective Measures | Responsibility | Improved Status: Measures Taken | Severity | Occurrence | Detection | Risk Priority Factor |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |

Now the effect of the failure is examined. This is the consequence the possible failure would have for the customer, which may be the next operation in the manufacturing process. By "Customer" is meant the Schonburger definition of the word.

Effect(s) of Failure - Where possible, express effect in terms of the product function. This will help to identify the severity of the consequence of the failure:

Excessive machining will be required

Generate excessive heat

Component will fracture

Having established all the possible effects of the failures, the causes need to be established. This is simply the reasons for the failures. List all the possible causes assigned to each failure mode. Care should be taken to ensure that the list is as inclusive as possible so that remedial effort can be aimed at al pertinent causes. Examples of causes might be:

Broken tooling

Worn Tooling

Wrong metallurgy

Machine settings

Inaccurate gauging

Inadequate process control

The overall objective of this exercise is to gather a good understanding by all the team members of the

possible failures together with their causes and effects.

## 4.5 CURRENT AND IMPROVED RISK FACTOR

The selected technique for FMEA analyses the current status of the potential failure, lists possible corrective measures and anticipates what the improved status will be. This is clearly demonstrated on the FMEA form.

To determine the risk factor three probabilities are taken into account:- 1) Occurence

2) Significance

3) Discovery

The Risk Priority Factor is simply a probability which is the product of these three probabilities.

Occurrence is a probability ranked from 1 to 10. The criteria to be considered in estimating the occurrence ranking is the probability that the cause will occur and this results in the indicated failure mode. The following table may be used as a guide line.

| CRITERIA | RANKING | PROBABILITY |
|---|---|---|
| REMOTE probability of occurrence | 1 | 1/10 000 |
| LOW probability of occurrence | 2 | 1/5 000 |
| | 3 | 1/2 000 |
| | 4 | 1/1 000 |
| | 5 | 1/500 |
| MODERATE probability of occurrence | 6 | 1/200 |
| HIGH probability of occurrence | 7 | 1/100 |
| | 8 | 1/50 |
| VERY HIGH probability of occurrence | 9 | 1/20 |
| CERTAINTY | 10 | 1/10 |

Significance is the estimate of the significance of the "effects of failure" to the customer on a 1 to 10 scale. The table below gives a helpful guide.

| CRITERIA | RANKING |
|---|---|
| UNREASONABLE to expect that the minor nature of this failure will have any noticeable effect on the customer | 1 |
| LOW significance ranking due to the minor nature of the failure. Only slight customer annoyance. | 2<br>3 |
| MODERATE failure which causes the customer dissatisfaction. Customer is made uncomfortable or is annoyed by the failure. | 4<br>5<br>6 |
| HIGH degree of customer dissatisfaction due to the nature of the fault. | 7<br>8 |
| FAILURE of the product to perform its purpose. Does not involve safety. | 9 |
| VERY HIGH significant failure involves potential safety problems | 10 |

Discovery is the probability of discovering the defect, caused by the failure identified, before the product leaves the manufacturing location, using the 1 to 10 scale. The following is a guide line.

| CRITERIA | RANKING | PROBABILITY |
|---|---|---|
| REMOTE. Defect is very obvious | 1 | 1/10 000 |
| LOW likelihood that the product is dispatched with the defect The defect is obvious | 2 | 1/5 000 |
| | 3 | 1/2 000 |
| | 4 | 1/1 000 |
| | 5 | 1/500 |
| MODERATE. Defect is easily identified | 6 | 1/200 |
| | 7 | 1/100 |
| | 8 | 1/50 |
| HIGH. The defect has subtle characteristics | 9 | 1/20 |
| VERY HIGH. The defect is latent and would not appear at manufacturing or inspection. | 10 | 1/10 |

The resultant risk priority factor is an integer in the range of 1 to 1000. Obviously the higher the number the higher the risk. This is used to set a priority rating for a plan of action which will address the more serious faults first. The plan of action must include the date of the next FMEA to ensure effective follow up.

## 4.6 SAFETY CRITICAL COMPONENTS

As a result of design FMEA carried out by the princliple manufacturers components which exhibit critical failure features are termed "Safety Critical". This implies that if the designed feature is not maintained the component could fail in its function, thereby causing or resulting in damage to machinery and/or injury and even loss of life.

To avert this situation all drawings and paperwork are to carry an identification symbol showing that the component is a "Safety Critical" item and the specific features that result in this are to be clearly identified.

Each manufacturer has his own "safety critical" symbol. For example one manufacturer uses an inverted triangle with the letter "S" on the inside.

All "Safety Critical" components are to

conspicuously display the following:-

1) The safety critical symbol is to be shown in the key of all "Safety Critical" drawings. The title is to indicate this and also the number of occurrences.

2) Print the number of safety critical features relevant to the component on the drawing in the designated area and identify each safety critical item adjacent to the actual position on the drawing. i.e.

Porosity Detection 

Hardness 160 - 190 BHN

This identification states that the design feature may not be altered in any way and should alteration be required for any reason whatsoever, written approval and subsequent drawing changes will be required.

3) All paper work relating to a "Safety Critical" components are to bear the safety critical stamp.

4) Quality Control are to carefully monitor all safety critical components and a traceable record of "measurements taken" kept.

## 4.7 CONCLUSION

As it can be seen this method is very subjective and open to all sorts of abuse. The skill to be developed in using this technique is to try to keep judgements consistent.

A good spin-off of FMEA analysis is that a good understanding of the component and the manufacturing process is gained by the evaluating team. This is also a dynamic process in that when all major defects are eliminated, minor defects begin to become significant and are addressed. This is simply yet another example of the ultimate quest for zero defect.

All motor manufactures require that component suppliers do process FMEAs, and is therefore very important to suppliers who want "A" ratings.

# 5 INFRASTRUCTURE OF THE QUALITY SYSTEM

## 5.1 PROVISION OF RESOURCES

The first step in defining Quality responsibilities is to establish a Quality Management Team (QMT). This consists of the Systems Manager, who is also appointed the Quality System Co-ordinator, the Foundry Manager, the Development Manager, the Metallurgist and the Production Manager. The function of the QMT is to attend to all the quality related matters affecting the drawing up and implementing of procedures which will satisfy the requirements of SABS 0157 Part 2 and to supplement it so that it will also satisfy the quality requirements of the various motor manufactures. This task will be achieved in four basic steps :-

* Quality Policy
* Objectives
* Standard Operating Procedures
* Works Instructions

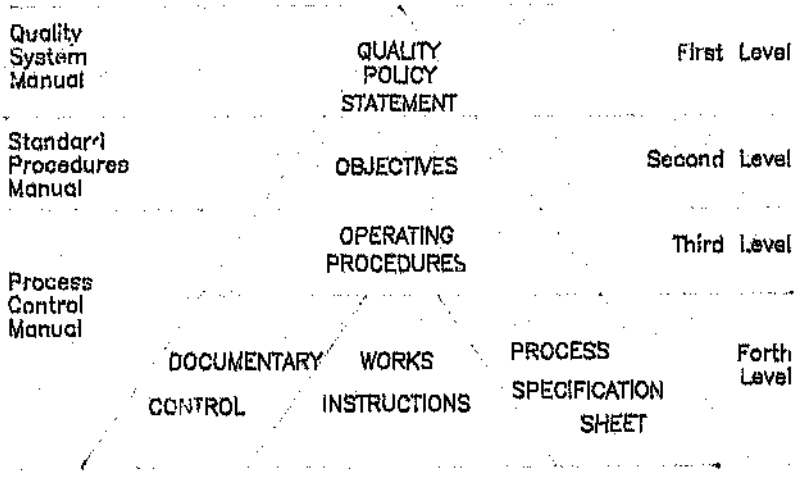
These four levels of documents focus on the product in increasing detail.

The procedure will be to draw the documents firstly in draft form, circulate them to all people concerned

for comment, and after gaining general consensus to prepare them in the standard format for approval by the Managing Director.

The diagram below depicts the general structure.

fig. 4.1




## 5.2 QUALITY POLICY

This statement provides a set of broad directional guidelines for the whole factory. It outlines managements expectations from the staff and indicates to the customers what they can expect.

A good Quality Policy should therefore include the following aims :-

* Steps to prevent defective work
* Preserve and improve the company's image
* Promote customer confidence and satisfaction
* Reduce scrap, rework and rectification
* Improve productivity

Following is the adopted policy of Auto Industrial

AUTO INDUSTRIAL QUALITY COMMITMENT

QUALITY is the number one operating priority in the Auto Industrial Group.

Our aim is to give top attention - top status - and top dedication in every decision we make - every action we take and every move we make.

This philosophy is to be implemented at every Auto Industrial Group site by adherence to the following three quality mandates:-

1) In order to maintain quality leadership in the markets we serve we will produce and deliver on time, products and services which conform to BABB 0157 part 2.

To achieve this goal each individuals contribution is a vital part of the overall effort. The emphasis on quality requires constant conscious commitment by each employee to "DO IT RIGHT FIRST TIME". Management is dedicated to creating conditions which will allow achievement of this goal.

By improving relationships and communications with the labour force and encouraging team spirit

throughout all levels of the company and to promote better efficiency and increased productivity by creating better and safer working conditions.

Signed Chief Executive.

5.3 OBJECTIVES

A serious time constraint on implementing the quality policy is that unless a B1 rating for QSK-01 can be achieved, components cannot be shipped to BMW irrespective of the actual quality standard achieved. BMW contributes significantly to the order book of Auto Industrial. This has to be achieved before the end of June '91. B1 rating requires SABS 0157 Part 2 to be operating, although an actual SABS audit can be completed at a later date.

Therefore the immediate objective is to concentrate on drawing up and implementing operating procedures and supplementing them with works instructions. At the same time it is required to implement data collecting systems so that process capabilities can be evaluated before the end of June, 1991.

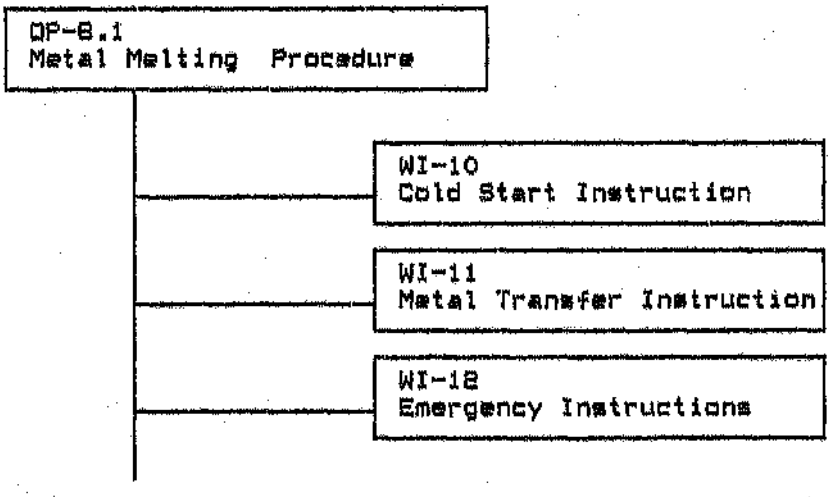
To achieve this the following programme has to be followed:-

| | Jan | Feb | Mar | Apr | May | Jun |
|---|---|---|---|---|---|---|
| Set up Monitor Systems | *** | ** | | | | |
| Basic Process Control | | **** | | | | |
| SABS 0157 part 2 | | *** | **** | **** | ** | |
| Process Experiments | | | *** | | | |

| | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Systems Effectiveness | | | | | ** | | * | | | **** | | | | | * | | | | | | | | |
| Process Capability | | | | *** | | | | | | | *** | | | | | * | | ** | | | | | |
| QSK-01 Assessment | | | | | | | | ** | | ** | | | *** | | | | | | | | | | |
| QSK-01 Audit | | | | | | | | | | | | | | | | | | | | ** | | | |

## 5.4 STANDARD OPERATING PROCEDURES

SABS 0157 Part 2 gives a guide to the minimum standard operating procedure requirements. Standard procedures apply to both quality systems as well as technical matters. The object is to spell out the broad basic quality criteria. More specific instructions which detail the exact instructions are to be included in specific works instructions for each topic. Each operating procedure may consist of many works instructions as depicted below




Operating instructions must also make reference to specific documentary and recording procedures. Each

document in the system must be numbered and blank masters appended to the operating procedures manual.

Operating procedures must also define both departmental and personal procedures. Every procedure and instruction must define who is responsible for implementing and controlling the procedure.

## 5.5 WORKS INSTRUCTIONS

Works instructions define in every possible detail the exact process and also the quality standards which apply. The works instruction may be viewed in three parts, ie. the Works Instruction (WI) itself, the recording document/Process Control Sheet (PCS) and the Process Specification Sheet (PSS).

The works instruction details the process in step form. The Production Manager will go through each step with the machine/process operator and ensure that he understands every detail. Although the system in fairly rigid all staff are encouraged to improve or simplify the process in which case it will be necessary to update the works instruction. However, the instructions must be specified particularly in the inspection standards so that short cuts which compromise quality will be avoided.

Each component Item is controlled by a unique Process Specification Sheet. See fig. (5.2). This

document gives the exact machine settings and the exact manufacturing procedure for each component. Critical measurements and requirements are highlighted in the inspecting standards. This gives the process/machine operator details of the exact requirements in easy to understand format.

Documentary control is in the form of Process Control Sheets, see fig. 5.2. Exact details of production qualities, delays, component changes, etc. are recorded.

# Process Specification Sheet

AIF Number | QA 11

Part Description:

Make: | Model:

Cstmr Dwg No:

(1) Material Specifications:--

Cstmr Spec: | AIF Spec:

Chemical Analysis

| C | Si | P | S | Mn | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | max |
| | | | | | | | | | | | min |

Max Furnace Temperature:

Cast Temperature: Max: Min:

Ladle Treatment:

(2) Casting Methods

Machine:

Core:

Strainer: | Mould Innoculant:

No. Components / Mould:

Machine Settings:--

Sand Timers -- Top Box Sec.

Bottom Box Sec.

Clamping Pressure: Top Bar

Clamping Pressure: Bottom Bar

Maximum Cooling Time: Min

Minimum Cooling Time: Min

Production Rate: Components / Hour

Notes

(3) Cores

Machine Settings:--

Gas Pressure P1: P2: P3:

Timers:-- Blow | Purge

Exhaust | Gas

Dip:

Production Rate: Components / Hour

(4) Finishing

Shot Blast

Band Saw

Fettle

(5) First Off Inspection

Visual Inspection:

Hardness:

Metallurgical Inspection:

Dimensional Check:

Notes

Drawing - Sketch

| Revision Dates | | | | | | |
|---|---|---|---|---|---|---|
| Revision Level: | | | | | | |
| Approved by: Factory Manager | | | | | | |
| Systems | | | | | | |
| Metallurgy | | | | | | |
| Development | | | | | | |

Compiled by: Date Issued:

# 6 DESIGN OF EXPERIMENT

## 6.1 BASIC PRINCIPLE OF A GREEN SAND PLANT

The physical nature of the "green sand" used in automatic moulding lines is very complex. Essentially it consists of a mixture of reprocessed sand, new sand, bentonite, coalduct, moisture and residual fines. The schematic diagram below shows the basic process.

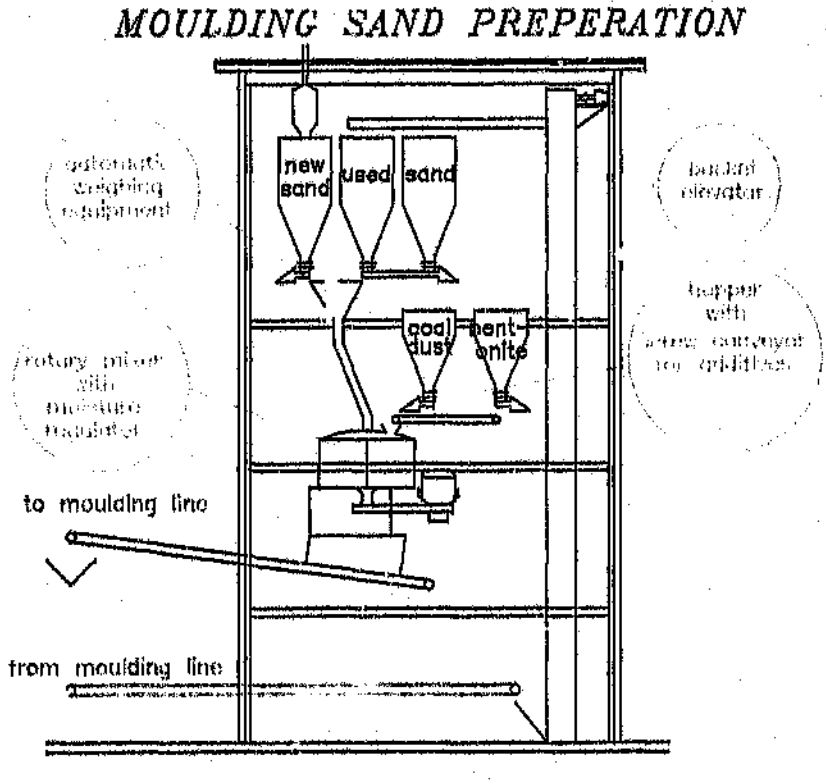
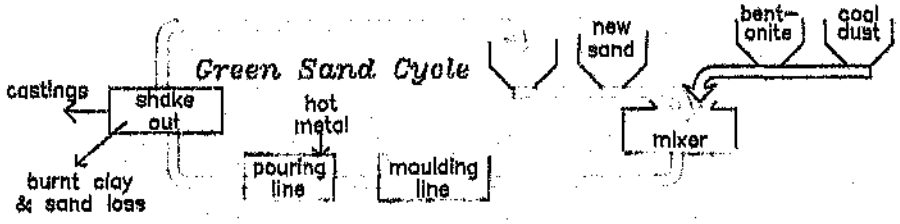



fig 6.1

New sand is introduced into the system to replace sand which is lost in the process and at the same time dilutes the build up of residual dead clay and other impurities.

fig 6.2




The cycle includes the addition of Coal Dust and Bentonite with each completed cycle. Hot Metal ignites (burns) the coal dust and sinters (kills) the clay. This results in the build up of "dead clay" and burnt coal dust "fines".

As impurities in the sand affects the desirable propeties of the sand these are carefully monitored. The quantity of coal dust in the system is monitored as the "Loss Of Ignition" (LOI) in a test which all the volitiles, after the moisture content has been removed, are burnt out. Dead clay is measured by means of a titration process while the fines are measured in a sieve test which also gives the average grain size definition of the sand.

The results of these tests are used to make corrections to the green sand. This human input element is necessary as the size and quantity of castings vary which obviously causes corresponding variations in the green sand makeup. Inconsistency in sand quality results initially in poor quality casting surfaces and ultimately in total inability to mould.

Dr. Schaarschmidt (1) claims that in his experience approximately 50% of castings scrapped can be attributed to variations in sand quality. The relatively limited experience gained in production casting at this point in time seems strongly to support this claim and, therefore, the need to study this process is very evident.

The most significant variables in the moulding "green sand" are summarised below:-

| | | |
|---|---|---|
| controllable variables | - | % recycled sand |
| | | % new sand |
| | | % bentonite |
| | | % coal dust |
| | | % water (moisture content) |
| | | mixing time |
| Uncontrolled variables | - | ambient temperature |
| | | atmospheric humidity |
| | | recycled sand temperature |
| | | loss of ignition (burnt |

coal)
production rate
variety of component
castings
introduction of core sand
build up of residual fines
impurities from the
atmosphere

The desirable characteristic required of the moulding sand are summarised below:-

| | | |
|---|---|---|
| High mould strength | - | rigid mechanical propeties |
| Mouldibility | - | ability to take on any shape |
| Flowability | - | ability to pour it into a mould |
| Inert and safe | - | no influence on the metallurgy or on people or equipment |
| Permeability | - | ability to vent off gasses and steam |

From this it can be seen that the demands on the moulding sand are very stringent and that in order to produce consistent high quality castings accurate sand technology data must be available.

The paradox in sand technology is the apparently conflicting requirements. Hard moulds which are ideal for dimensional stability will have poor flow characteristics. Some compromise in characteristics will, therefore, have to be made - and perhaps a resulting optimum can be estimated.

The concept behind further investigation into "green sand" is to establish not only the effects and influences of the main controlable variables but also the effects of interactions between these variables. There is little that can be done about the uncontrollable variables except to keep them as consistent as possible so that their respective effects will not unduly degrade the experiment.

## 6.2 PURPOSE AND METHODOLOGY

If the sand were to be kept consistent, then the target variables would be the additives i.e. bentonite, coal dust and moisture. The quality, reflected in the consistency, of these ingredients is very good and is generally accepted as the industrial standard. The justification for not including the sand, at this stage, is that in itself it is inert, although it may be the carrier of impurities. This problem will be adressed separately.

With this format of three variables complete block factorial experiment is feasible and desirable as the interactions also need to be investigated.

The model for the three-factor experiment is given by

$$Y_{ijkl} = \mu + a_i + b_j + c_k + (ab)_{ij} + (ac)_{ik} + (bc)_{jk} + (abc)_{ijk} + \epsilon_{ijkl}$$

To facilitate a systematic tabular technique the Yates (2) methodology is used for deriving the

factorial effects. The format which is shown below is easily programmed onto a spreadsheet for quick and accurate analysis. This is justified because with two replicates, 16 evaluations need to be made.

The effect of these variables will be measured by the following tests:-

1) compactibility - % of compact by applying 8 controlled rams
2) shear - kN load required to shear the test sample
3) crush - kN load required to crush the test sample
4) tensile - kN load required to snap the test sample
5) hardness - hardness of the test sample

This, therefore, implies that 5 times two replicated sets of tests are to be conducted for each test condition.

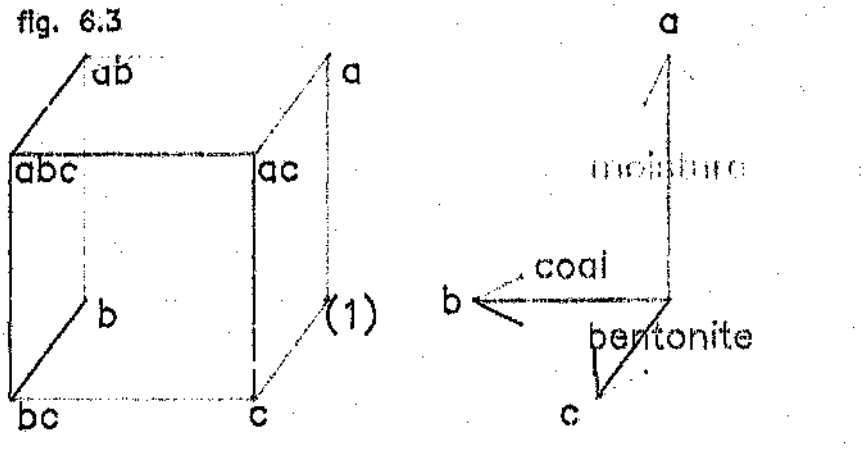
Table 6.1 Yates Method

| | (1) | (2) | (3) | Ident. |
|---|---|---|---|---|
| (1) | (1)+a | (1)+a+b+ab | (1)+a+b+ab+c+ac+bc+abc | Total |
| a | b+ab | c+ac+bc+abc | a-(1)+ab-b+ac-c+abc-bc | A contrast |
| b | c+ac | a-(1)+ab-b | b+ab-(1)-a+bc+abc-c-ac | B contrast |
| ab | bc+abc | ac-c+abc-bc | ab-b-a+(1)+abc-bc-ac+c | AB contrast |
| c | a-(1) | b+ab-(1)-a | c+ac+ab+abc-(1)-a-b-ab | C contrast |
| ac | ab-b | bc+abc-c-ac | ac-c+abc-bc-a+(1)-ab+b | AC contrast |
| bc | ac-c | ab-b-a+(1) | bc+abc-c-ac-b-ab+(1)+a | BC contrast |
| abc | abc-bc | abc-bc-ac+c | abc-bc-ac+c-ab+b+a-(1) | ABC contrast |

The experiment requires two conditions for each of the variables. High and low states will be chosen from the daily sand plant control system. Summarised below are these conditions together with diagram depicting the design concept.

| | | low | high |
|---|---|---|---|
| a | % Moisture | 2,5% | 4,0% |
| b | Coal Dust | 4,0% | 10,0% |
| c | Bentonite | 8,0% | 7,0% |

fig. 6.3



## 6.3 RESULTS & ANALYSIS

An important condition of the experiment is that it is run in a completely random manner. The first two column of table 6.2 shows the actual order in which the experiment was run. Environmental conditions were reasonably consistent with ambient temperature between 19 and 20 degrees centigrade and a humidity of 65 percent. A uniform sample of new sand was used for all the tests. Bentonite and coal dust samples were taken from new uncontaminated stock. Mixing time was held constant at 10 minutes, which is the laboratory mixers manufactures recommended time. 1 Kilogramme samples were mixed for each of the 16 test conditions.

The experiment results for each of the five tests displayed in the form of a matrix for easy reference.

Table 6.2 Test Results

| Experiment Test Results | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Random Run | | Std. Ord. | Compact. | | Shear | | Crush | | Tensile | | Hardness | |
| | | | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| 7 | 14 | (1) | 40 | 39 | 15 | 14 | 20 | 22 | 0.8 | 0.8 | 37 | 40 |
| 6 | 3 | a | 59 | 57 | 15 | 25 | 19 | 22 | 0.9 | 1.3 | 43 | 42 |
| 16 | 10 | b | 36 | 36 | 11 | 15 | 16 | 19 | 0.4 | 0.8 | 37 | 41 |
| 13 | 15 | ab | 56 | 55 | 17 | 17 | 20 | 21 | 1.0 | 0.9 | 43 | 43 |
| 11 | 2 | c | 24 | 23 | 15 | 13 | 25 | 18 | 0.9 | 0.4 | 30 | 25 |
| 4 | 8 | ac | 56 | 47.5 | 31 | 33 | 33 | 33 | 2.1 | 1.7 | 50 | 45 |
| 9 | 5 | bc | 25 | 25 | 15 | 14 | 19 | 12 | 0.6 | .4 | 30 | 27 |
| 12 | 1 | abc | 44 | 44 | 30 | 26 | 33 | 28.5 | 2.1 | 1.5 | 45 | 34 |

Table 6.3 shows the method used for analysing the results. This information was fed into a Lotus 123 spread sheet, the results of which are shown on Table 6.4

Table 6.3 Method of analysis.

| Test Type : | | | Page___of Pages___ | | | | |
|---|---|---|---|---|---|---|---|
| Treat. Comb. | Replicate 1 | Replicate 2 | Total Treat. | (1) | (2) | (3) | Sum of Squares |
| (1) | | | | | | | |
| a | | | | | | | |
| b | | | | | | | |
| ab | | | | | | | |
| c | | | | | | | |
| ac | | | | | | | |
| bc | | | | | | | |
| abc | | | | | | | |

| Source of Variance | Sum of Squares | Degrees of Freedom | Mean Square | Computed f |
|---|---|---|---|---|
| Main Effect | | | | |
| A | | | | |
| B | | | | |
| C | | | | |
| Two-factor Interaction | | | | |
| AB | | | | |
| AC | | | | |
| BC | | | | |
| Three-factor Interactions | | | | |
| ABC | | | | |
| Error | | | | |
| Total | | | | |

TEST: COMPACTABILITY

| TREAT. COMB. | REP 1 | REP 2 | TOTAL TREAT | YATES METHOD (1) | (2) | (3) | SUM OF SQUARES | EFFECT & INTERACTION | DoF | MEAN SQ | f | f.05(1,8) = 5.32 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) | [illegible] | [illegible] | 79 | 195 | 378 | 667 | | | | | | |
| a | [illegible] | [illegible] | 116 | 183 | 289 | 171 | 1817 | A | 1 | 1817 | 367 | ***** |
| b | [illegible] | [illegible] | 72 | 151 | 76 | -25 | 38 | B | 1 | 38 | 8 | ***** |
| ab | [illegible] | [illegible] | 111 | 138 | 95 | -17 | 17 | AB | 1 | 17 | 3 | |
| c | [illegible] | [illegible] | 47 | 37 | -12 | -90 | 501 | C | 1 | 501 | 101 | ***** |
| ac | [illegible] | [illegible] | 104 | 39 | -13 | 19 | 21 | AC | 1 | 21 | 4 | |
| bc | [illegible] | [illegible] | 50 | 57 | 2 | -1 | 0 | BC | 1 | 0 | 0 | |
| abc | [illegible] | [illegible] | 88 | 38 | -19 | -21 | 26 | ABC | 1 | 26 | 5 | |
| TOTALS | 340 | 327 | 667 | | | ERROR | 40 | | 8 | 5 | | |
| | | TSSQ | 2489 | | | | | | 16 | | | |

TEST: SHEAR

| TREAT. COMB. | REP 1 | REP 2 | TOTAL TREAT | YATES METHOD (1) | (2) | (3) | SUM OF SQUARES | EFFECT & INTERACTION | DoF | MEAN SQ | f |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) | [illegible] | [illegible] | 29 | 69 | 129 | 306 | | | | | |
| a | [illegible] | [illegible] | 40 | 60 | 177 | 82 | 420 | A | 1 | 420 | 47 ***** |
| b | [illegible] | [illegible] | 26 | 92 | 19 | -16 | 16 | B | 1 | 16 | 2 |
| ab | [illegible] | [illegible] | 34 | 85 | 63 | -12 | 9 | AB | 1 | 9 | 1 |
| c | [illegible] | [illegible] | 28 | 11 | -9 | 48 | 144 | C | 1 | 144 | 16 ***** |
| ac | [illegible] | [illegible] | 64 | 8 | -7 | 44 | 121 | AC | 1 | 121 | 14 ***** |
| bc | [illegible] | [illegible] | 29 | 36 | -3 | 2 | 0 | BC | 1 | 0 | 0 |
| abc | [illegible] | [illegible] | 56 | 27 | -9 | -6 | 2 | ABC | 1 | 2 | 0 |
| TOTALS | 149 | 157 | 306 | | | ERROR | 71 | | 8 | 9 | |
| | | TSSQ | 784 | | | | | | 16 | | |

TEST: CRUSH

| TREAT. COMB. | REP 1 | REP 2 | TOTAL TREAT | YATES METHOD (1) | (2) | (3) | SUM OF SQUARES | EFFECT & INTERACTION | DoF | MEAN SQ | f |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) | [illegible] | [illegible] | 42 | 83 | 169 | 361 | | | | | |
| a | [illegible] | [illegible] | 41 | 76 | 202 | 89 | 214 | A | 1 | 214 | 24 ***** |
| b | [illegible] | [illegible] | 35 | 109 | 5 | -24 | 36 | B | 1 | 36 | 4 |
| ab | [illegible] | [illegible] | 41 | 93 | 84 | 15 | 13 | AB | 1 | 13 | 1 |
| c | [illegible] | [illegible] | 43 | -1 | -7 | 43 | 113 | C | 1 | 113 | 13 ***** |
| ac | [illegible] | [illegible] | 66 | 6 | -17 | 49 | 147 | AC | 1 | 147 | 17 ***** |
| bc | [illegible] | [illegible] | 31 | 23 | 7 | -10 | 6 | BC | 1 | 6 | 1 |
| abc | [illegible] | [illegible] | 62 | 31 | 8 | 1 | 0 | ABC | 1 | 0 | 0 |
| TOTALS | 185 | 176 | 361 | | | ERROR | 71 | | 8 | 9 | |
| | | TSSQ | 598 | | | | | | 16 | | |

TEST: TENSILE

| TREAT. COMB. | REP 1 | REP 2 | TOTAL TREAT | YATES METHOD (1) | (2) | (3) | SUM OF SQUARES | EFFECT & INTERACTION | DoF | MEAN SQ | f |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) | [illegible] | [illegible] | 2 | 4 | 6 | 16 | | | | | |
| a | [illegible] | [illegible] | 2 | 2 | 10 | 6 | 2 | A | 1 | 2 | 17 ***** |
| b | [illegible] | [illegible] | 1 | 6 | 0 | -2 | 0 | B | 1 | 0 | 2 |
| ab | [illegible] | [illegible] | 1 | 6 | 6 | -1 | 0 | AB | 1 | 0 | 0 |
| c | [illegible] | [illegible] | 1 | 1 | -2 | 4 | 1 | C | 1 | 1 | 8 ***** |
| ac | [illegible] | [illegible] | 4 | -0 | -1 | 5 | 1 | AC | 1 | 1 | 12 ***** |
| bc | [illegible] | [illegible] | 1 | 3 | -1 | 1 | 0 | BC | 1 | 0 | 1 |
| abc | [illegible] | [illegible] | 4 | 3 | 0 | 1 | 0 | ABC | 1 | 0 | 0 |
| TOTALS | 8 | 8 | 16 | | | ERROR | 1 | | 8 | 0 | |
| | | TSSQ | 6 | | | | | | 16 | | |

TEST: HARDNESS

| TREAT. COMB. | REP 1 | REP 2 | TOTAL TREAT | YATES METHOD (1) | (2) | (3) | SUM OF SQUARES | EFFECT & INTERACTION | DoF | MEAN SQ | f |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) | [illegible] | [illegible] | 77 | 162 | 326 | 612 | | | | | |
| a | [illegible] | [illegible] | 88 | 164 | 286 | 76 | 360 | A | 1 | 360 | 30 ***** |
| b | [illegible] | [illegible] | 78 | 150 | 16 | -12 | 9 | B | 1 | 9 | 1 |
| ab | [illegible] | [illegible] | 86 | 136 | 62 | 18 | 20 | AB | 1 | 20 | 2 |
| c | [illegible] | [illegible] | 58 | 8 | 2 | 40 | 100 | C | 1 | 100 | 8 ***** |
| ac | [illegible] | [illegible] | 95 | 8 | -14 | 46 | 132 | AC | 1 | 132 | 10 ***** |
| bc | [illegible] | [illegible] | 57 | 40 | 0 | -16 | 16 | BC | 1 | 16 | 1 |
| abc | [illegible] | [illegible] | 79 | 22 | -18 | -18 | 20 | ABC | 1 | 20 | 2 |
| TOTALS | 316 | 297 | 612 | | | ERROR | 103 | | 8 | 13 | |
| | | TSSQ | 781 | | | | | | 16 | | |

## 6.4 EFFECTS AND INTERACTIONS

The significant results are tabulated below in table 6.5

Table 6.5 Effects and Interactions Summary

| | Compact. | Shear | Crush | Tensile | Shatter |
|---|---|---|---|---|---|
| Moisture | Sig. | Sig. | Sig. | Sig. | Sig. |
| Coal | Sig. | | | | |
| Bentonite | Sig. | Sig. | Sig. | Sig. | Sig. |
| Moisture + Coal | | | | | |
| Moisture + Bent. | Sig. | Sig. | Sig. | Sig. | Sig. |
| Bentonite + Coal | | | | | |
| Moist+Bent+Coal | | | | | |

The effects of both Water and Bentonite are prominently significant on all the physical properties of green sand. Surprisingly, is the insignificance of the coal dust except in its effect of diluting the moisture, possibly the reason why there is no three factor significance.

Noteworthy is the pronounced significance of moisture content on compactibility. This together with the reducing effect of the coal confirms the validity of the compactibility test as a control mechanism.

As coal has no real positive significant influence on the physical properties and it is expensive, it must be kept to an absolute minimum. Coal apparently plays an important roll in the surface finish of the casting so that additional experimentation in this area may be necessary.

# 7 CAPABILITY STUDY

## 7.1 DEFINITION

The capability study is an analytical methodology for predicting the output consistency of a machine or process and an aid to diagnostics when the output is predicted beyond specification limits (7). Techniques available for the analysis vary from graphic techniques using prepared forms through techniques using calculator to specialized computer programs.

Ideally capability studies should be carried out at various stages of a machines life cycle - from pre-delivery and at regular intervals thereafter.

Capability studies should include equipment - tooling - material - operator combination to ensure consistency to specification under production conditions.

Finally, process or machine studies may be used in problem solving when out of specification conditions are found to help diagnose the cause of the problem. The technique is to establish all the probable causes (assignable causes) of variability and then to analyze them one at a time monitoring improvements.

## 7.2 METAL HARDNESS MEASUREMENT

In castings hardness is one of the important

physical properties monitored. Hardness is tested by means of a Brinell Hardness tester. A carbide ball of known diameter is pressed under a control load onto the test surface causing a small indentation. The diameter of this impression is measured by means of a calibrated scope. A look up table gives a correlation between the impression diameter and the brinell hardness. A more accurate method for measuring the diameter is using a magnified shadow graph and digital calipers. The latter equipment is only available at Auto Industrial.

## 7.3 DISC BRAKE CASE STUDY

Specifications for the AIF 852 Disc Brake, (See Photograph 18) which is made from a special high carbon steel, calls for a brinell hardness of between 160 and 200. The customer requires 100% hardness testing for the first three production batches of at least a quantity of 500 per batch.

A trial batch of approximately 250 discs were run and subjected to 100% hardness testing using the shadow graph method.

Standard statistical analysis of the results are shown in Fig. 7.1, 7.2 and Table 7.1 over leaf

Of the 246 actual discs, 4 were completely out of specification - two too hard and two too soft.

The average hardness of measured was 185.2 with a reasonable normal distribution. One important fact is

fig 7.1

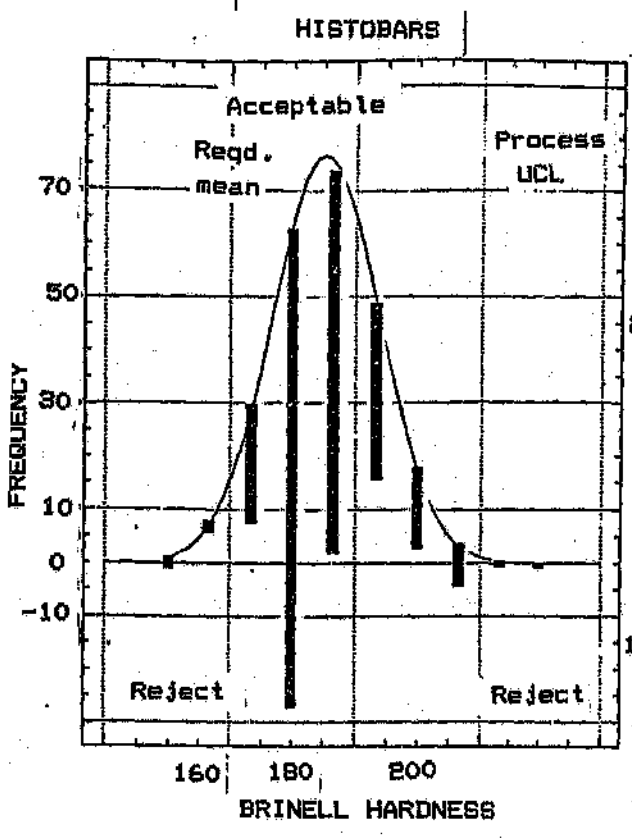



fig 7.2

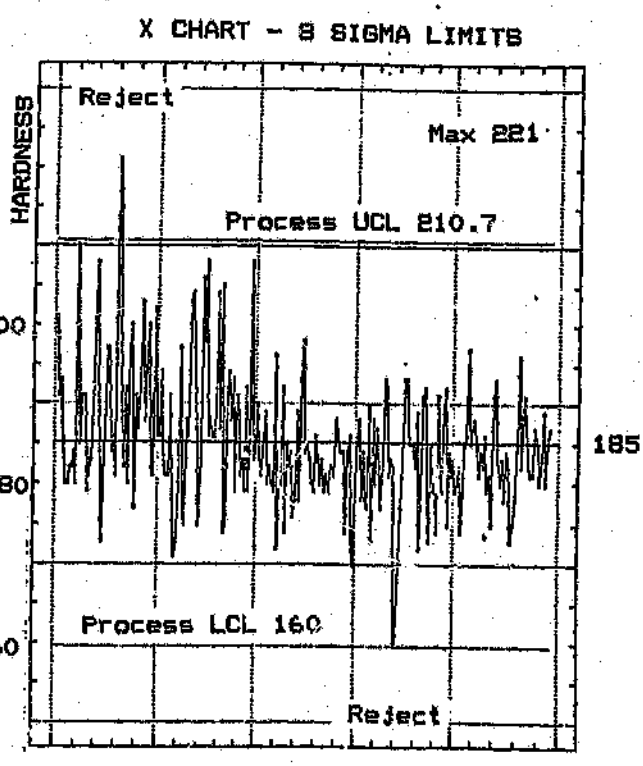



table 7.1 Statistical Analysis

| | |
|---|---|
| Sample size | 246 |
| Average | 185.207 |
| Median | 184 |
| Mode | 182 |
| Geometric mean | 185.017 |
| Variance | 72.467 |
| Standard deviation | 8.51276 |
| Standard error | 0.542754 |
| Minimum | 160 |
| Maximum | 221 |
| Range | 61 |
| Lower quartile | 180 |
| Upper quartile | 189 |
| Interquartile range | 9 |
| Skewness | 0.847816 |
| Standardized skewness | 5.42867 |
| Kurtosis | 2.01408 |
| Standardized kurtosis | 6.44805 |

that the hardness is measured at the surface while the customer specification call for a core (center) hardness. A correction factor of -7 units can therefore be applied, which makes the data very close to the desired theoretical mean of 180.

This, however, still gives an definite failure of four component with several border line cases and a spread which is too broad. Any slight shift in the process will result in far too higher failure rate. The characteristic of the distribution need to be altered to a steeper curve.

## 7.4 RECOMMENDATIONS

To reduce the spread the process will have to be tightened. The following recommendations are therefore made:-

* Very tight control of the metal carbon content - record chemical analysis and make up analyses
* Write specific Process Specification Sheet for the rate and method of carbon addition to the furnace.
* Record pouring temperature and time taken to fill mould, i.e. X Chart for pouring times/temperature
* Specify maximum mould cooling time
* Detail inspection of batch "First Off" and every twenty boxes there after.
* Draw up control chart for hardness testing.

## 7.5 SECOND RUN

Results of the second run were not as good as expected. Although there were no rejects, i.e. out of hardness specifications, the variability had increased significantly to 127.1

Before running any farther trials complete anslysis of the problem situation - all the systems - including the component specifications needs to be investigated.

## 7.6 REVIEW OF THE PROBLEM SITUATION

The specification for this component calls for a hardness of between 160 and 200 and also a percentage carbon content of between 3.7% and 3.9%. This is a problem.

To determine the carbon content of the molten metal, one third of the percentage of silicon and phosphorus must be subtracted from the carbon equivalent. The silicon content is approximately 2% with a negligible amount of phosphorus present, so that 0,67% should be deducted from the carbon equivalent to determine the carbon content. Typically carbon equivalent of 4.3% is desired. This gives a carbon content of 3.6%. But over 3.5% carbon becomes unstable in the molten metal resulting in undesolved carbon being present.

This means that the carbon can only be at the

absolute lower limit which makes effective control very difficult. At this limit carbon is oxidized very rapidly reducing significantly the shelf life of the metal. The customer has been made aware of this problem.

The next problem is to control the casting cooling time in the mould. The longer the casting is left in the mould the slower the cooling and the softer the casting will be. The object is to reduce the hardness spread by allowing equal cooling duration to all the castings moulds.

The problem is that the moulding machine automatically feeds the cooling moulds through a fixed cooling lane. Any stoppage or interruption like waiting for metal, results in a corresponding extension to the cooling time. This implies that the machine must run at a constant rate - a condition which is very difficult to achieve. Usually the cooling time is not critical. The Kunkel Wagner automatic moulding line certainly does not lend itself to "short circuiting" the cooling lanes.

Metal delivery temperature and pouring rate is well under control. This aspect is under control and parameters recorded onto charts to verify the status.

The procedure of carbon introduction into the melt furnace has been documented on the process specification sheet.

In the following test run the cooling times are

to be recorded. Comparisons of hardness and cooling times will be made to see if some correlation is present.

## 7.7 THIRD RUN

During this run the knockout time was recorded. This was achieved by short-circuiting the cooling lanes and following each mould box to the knock-out station. The castings were then followed through the shake out and placed in sequence for hardness treating after they were cool enough to handle.

Results are as follows:

| Number | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Time(min) | 18 | 23 | 26 | 27 | 28 | 48 | 46 | 48 | 49 | 53 | 55 |
| Hardness | 197 | 186 | 186 | 182 | 188 | 178 | 172 | 174 | 172 | 176 | 170 |

continued

| Number | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Time | 56 | 35 | 37 | 38 | 39 | 40 | 18 | 19 | 20 | 22 | 23 |
| Hardness | 170 | 182 | 180 | 180 | 180 | 188 | 197 | 195 | 188 | 180 | 188 |

Analysis of this data is as follows:

1. Regression Analysis - Linear Model: Y = a+bX

| Parameter | Estimator | Standard Error | T Value | Prob. Level |
|---|---|---|---|---|
| Intercept | 298.628 | 25.7438 | 11.6 | 0 |
| Slope | -1.4441 | 0.14078 | -10.3 | 0 |

B. Analysis of Variance

| Source | Sum of Squares | DoF | Mean Square | F-Ratio | Prob. |
|---|---|---|---|---|---|
| Model | 9054.6573 | 1 | 9054.6573 | 105.221 | 0 |
| Error | 580.6154 | 20 | 29.0308 | | |
| Total(Corr) | 9635.2727 | 21 | | | |

Correlation Coefficient = -0.9167

Std. Error of Estimate = 5.3880

R-squared = 84.08 percent

8. Graph - Casting Cooling Characteristic

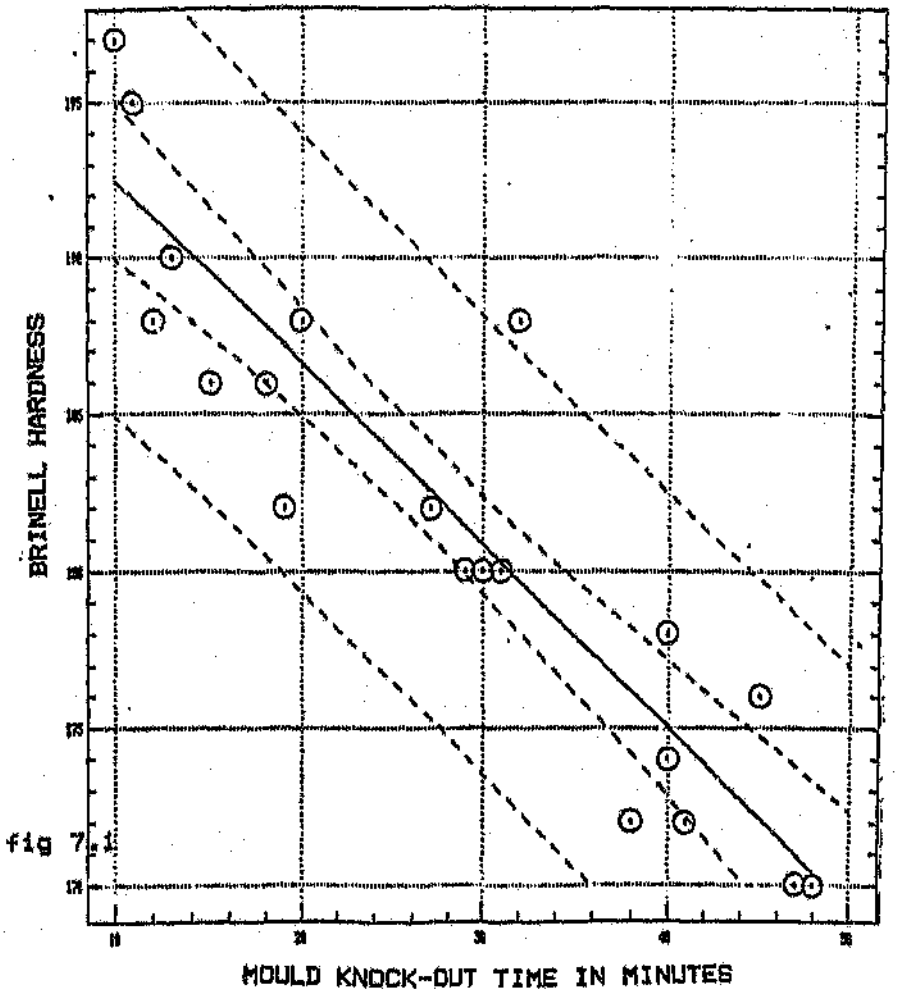



fig 7.1

From this it can be seen that there is reasonable correlation between hardness and knock-out time. Solification of the metal in the mould is completed after about 10 minutes, with pouring temperatures of 1400 degrees centigrade. However, at this stage the metal is likely to be damaged (distorted) in the shake-out as it is still too soft. After 16 minutes the casting will be sufficiently hard to avoid this risk.

Knock-out times of between 16 and 22 minutes will give the desired effect. This will produce castings in the hardness range of 185 to 195 which is sufficiently far enough away from the minimum of 160.

But the method used to achieve these test results is not practical for production purposes. The second moulding machine, which is being commissioned at present, will be far more suitable for this process.

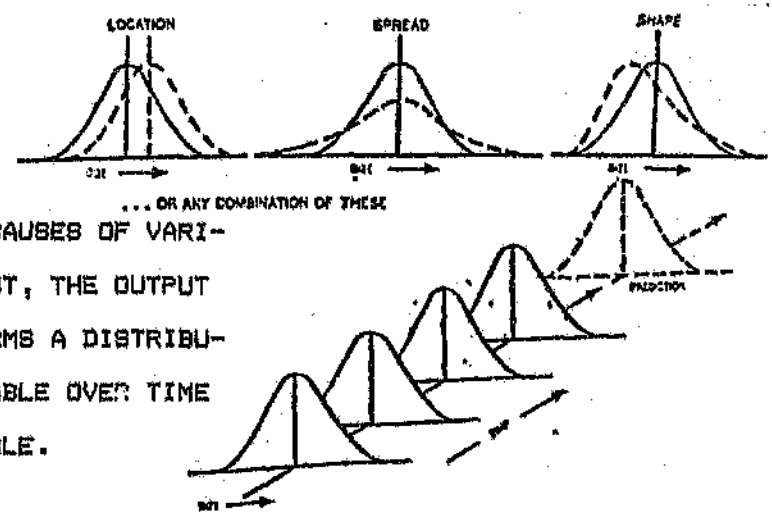
The present process is therefore not capable of meeting the specified quality requirements.

# 8 PROCESS CONTROL

## 8.1 PURPOSE

Dr. Walter A. Shewhart (8) states "Measured quality of manufactured product is always subject to a certain amount of variation as a result of chance. Some stable 'system of chance causes' is inherent in any particular scheme of production and inspection. Variation within this stable pattern is inevitable. The reasons for variation outside this stable pattern may be discovered and corrected."

VARIATION IN DISTRIBUTION




IF ONLY COMMON CAUSES OF VARIATION ARE PRESENT, THE OUTPUT OF A PROCESS FORMS A DISTRIBUTION THAT IS STABLE OVER TIME AND IS PREDICTABLE.



IF SPECIAL CAUSES OF VARIATION ARE PRESENT, THE PROCESS OUTPUT IS NOT STABLE OVER TIME AND IS NOT PREDICTABLE.

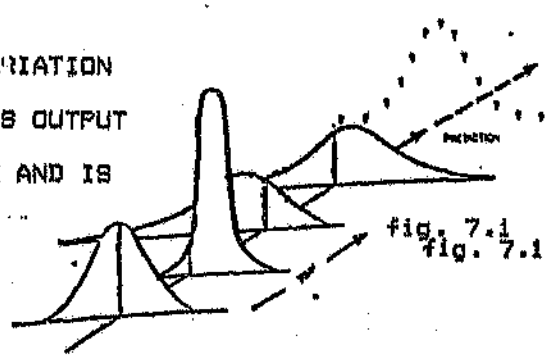
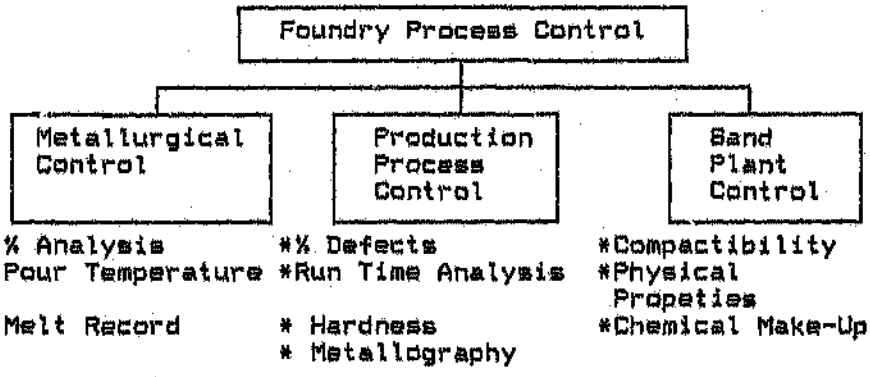


fig. 7.1
fig. 7.1

In order to effectively use process control as a means of quality assessment, it is important to understand the concept of variation. The diagram on the previous page adequately explains this concept in relation to Shewart's definition of process control.

Process control in the foundry may be classified into three dominant areas namely Metallurgical Control, Production Process Control and Sand Plant Control. Each of these functional areas is under its own management allowing for focussed specialisation each in their respective domain.

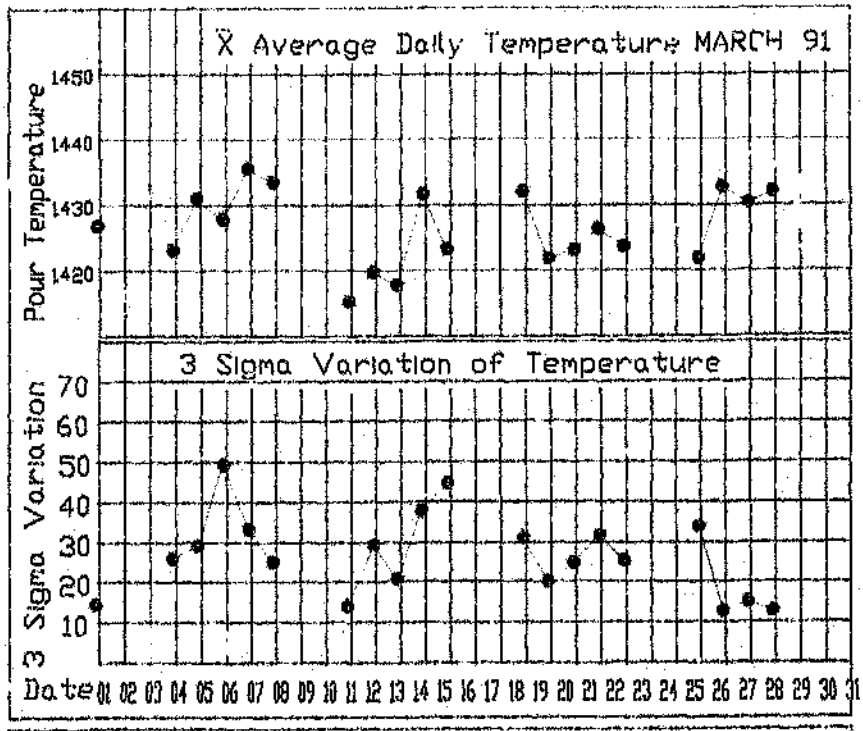



Therefore, to outline the details each control aspect will be examined separately.

## 8.2 METALLURGICAL CONTROL

% Chemical analysis, Pour temperature and Melt record are the most important control factors in metallurgical control. The Melt record, as the name implies, is the hard copy record of the melting process. A separate record book is kept for each furnace. All raw material additions to the furnace and corrected metal ladle transferred are recorded together with respective chemical analysis and delivery temperatures for each transaction. The chemical analysis is verified against the recipe, which obviously varies for different product groups i.e grey iron, high carbon, etc. Chemical analyses are therefore controlled within these groups. The one common element in casting is the mould pouring temperature and as it is a very critical element manufacturing process, process control systems were implemented.

Figure 8.2 shows the results of monitoring the daily average temperature for each ladle delivered to the pouring line for the months of March and April. The process was initially very unstable. This can be seen by the relatively high variations in the three sigma plot. After implementing effective control measures to reduce variations in delivery temperature a steady improvement is observed.


X̄ Average Daily Temperature MARCH 91
Pour Temperature
1450
1440
1430
1420
3 Sigma Variation of Temperature
3 Sigma Variation
70
60
50
40
30
20
10
Date 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

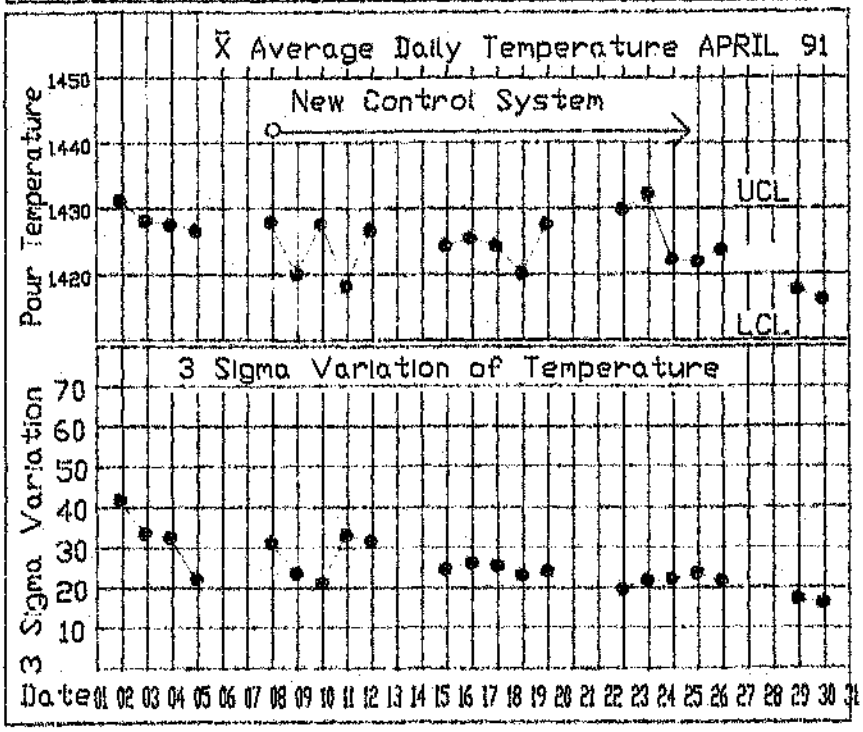

X̄ Average Daily Temperature APRIL 91
New Control System
UCL
LCL
Pour Temperature
1450
1440
1430
1420
3 Sigma Variation of Temperature
3 Sigma Variation
70
60
50
40
30
20
10
Date 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

Fig. 8.2

## 8.3 SAND PLANT CONTROL

The preparation of green sand is of particular interest in terms of process control. As has been pointed out it is of paramount importance in producing quality castings.

Sand must meet several specifications. Moisture content, total combustibles, permeability, compactability, tensile strength, percent clay, fines, etc. are characteristics regularly measured.

Of all these properties the one which concerns production most often is compactability which, in a way summarises several properties of the sand.

Compactability is affected by the amount of moisture, grain size distribution, percentage clay and in turn reflects how permeable the mould will be to escaping gases, resistance to erosion by hot metal and how strong the mould will be.

A sample is taken from each 800 kilogramme batch of green sand produced and a compactibility test taken. At normal production about thirty batches are produced per hour so that up to 180 batches may be produced in a shift. These readings are logged and plotted on a prepared chart.

Fig. 8.3 shows the plot of compactability for each batch on January, 21 and March, 21. One of the problems with this automatic green sand plant equipment

is that the operator can override the moisture measuring probe which often leads to over correction of minor moisture drifts. This condition is clearly evident in the January control chart. Note the improvement in the March control chart simply by less interference with the moisture control.

The average and the three sigma limits for the day are calculated and plotted. Results obtained are shown on the following pages. Once again evidence of control is demonstrated by the narrowing of the limits.

Fig. 8.4 shows the X plot together with the 3 sigma limits and the calculated average upper control limit and lower control limit. This gives a process capability over that period of 46.0% - 32.9% = 13.1% i.e. capable of producing within +- 6.5%. Also shown is the range and the 3 sigma range for the corresponding daily averages.

The problem is that the process desires a compactibility of between 40 and 36 for consistency in the automatic moulding line.

After limiting the use of the manual control facility to extreme emergency cases only, there is a definite improvement in results. Fig 8.5 demonstrates this.

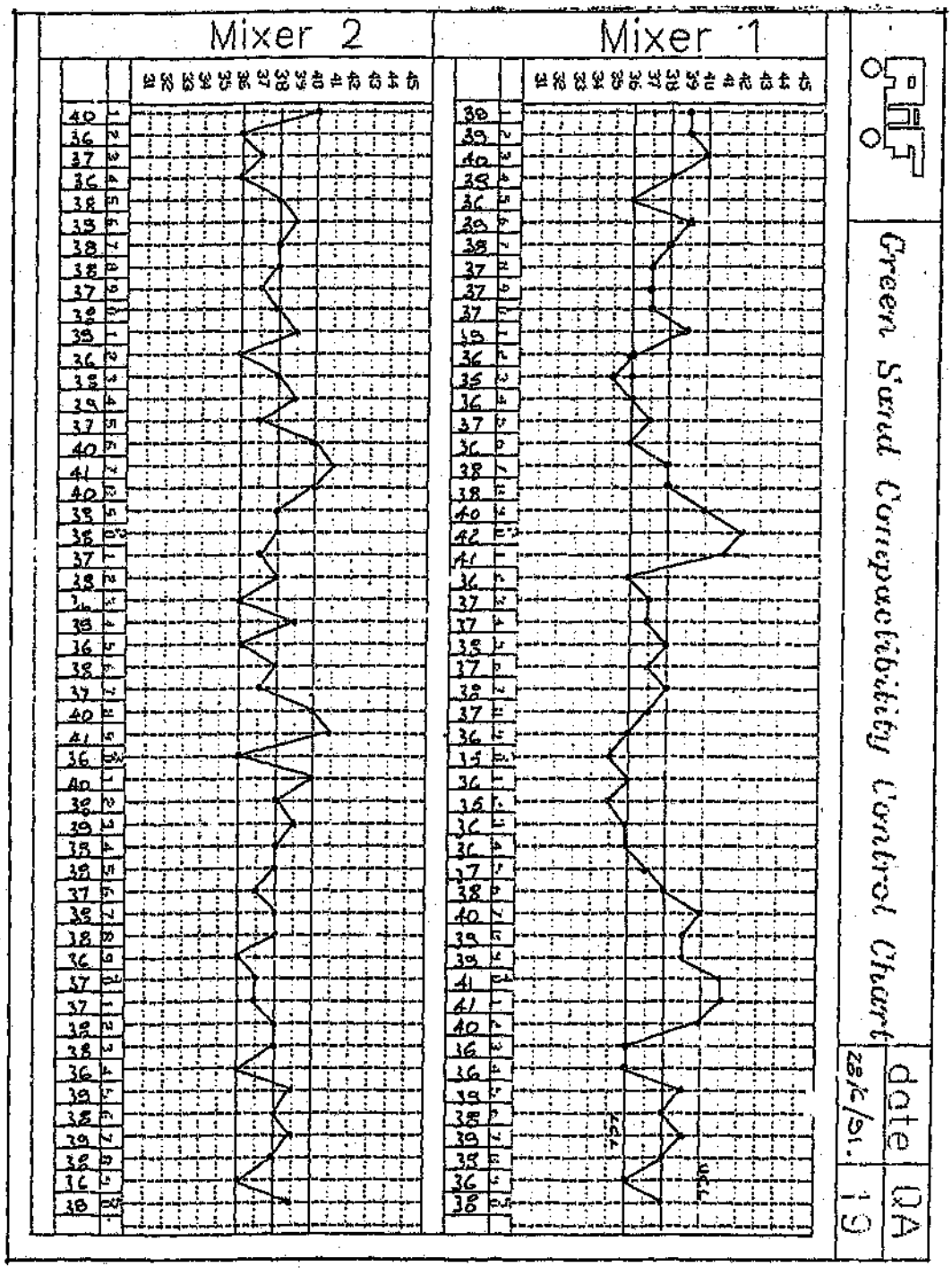

Mixer 2
Mixer 1
Green Sand Compactibility Control Chart
date
QA
19

Fig. 8.3

## 8.4 PRODUCTION PROCESS CONTROL

Monitoring the number of defects (Scrap) is a very important quality control function. This is the acid test of quality effectiveness Unfortunately much of the work being done at present is in product development. This results in an abnormally high amount of test runs and trials proving processes, procedures, metallurgy, chemistry, equipment, moulds, machinery, etc. being done. Usually this involves short runs producing less than 100 components. Therefore, in determining percentage rejects only production batches in excess of 100 components are considered, effectively filtering out most trials.

In considering the most suitable forms of defect control, the follows factors are significant:-

* batches varying vastly in quantity i.e 250 to 2500
* components varying in size
* components varying in complexity - difficult shapes
* some components require core
* different metal types
* multi cavity moulds
* differing run frequency
* different hardness requirements

The only chart which will accommodate these characteristics is the P-CHART. The method used was referenced from Grant & Levenworth (6)

A data base consisting quantities produced, and total quantities scrapped was set up. Shown in table 8.1. This information is used to determine the fraction (percentage) limits

Control limit is determined as follows:-

$$UCL = \bar{p} + 3\sqrt{(p(1-p)/n)}$$

where $\bar{p} = \Sigma r_i / \Sigma n_i$

The control chart for this is shown in Fig. 8.6. The upper control limit is calculated (lower control limit is meaningless). All points out of the control limit are investigated.

Table 8.1 Scrap p-Chart Data

| Batch Number | Alf Number | Qty Prod. | Qty Scrap | Fract. Defect | UCL | Batch Number | Alf Number | Qty Prod. | Qty Scrap | Fract. Defect | UCL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| APRIL | | | | | | 113E91 | 919R | 215 | 7 | 0.033 | 0.068 |
| 3D91 | 919R | 604 | 231 | 0.382 | 0.168 | 114E91 | 919R | 291 | 0 | 0 | 0.068 |
| 3D91 | 919L | 500 | 268 | 0.536 | 0.168 | 114E91 | 919L | 294 | 18 | 0.061 | 0.068 |
| 4D91 | 220/4 | 172 | 0 | 0 | 0.168 | 116E91 | 334 | 540 | 33 | 0.061 | 0.068 |
| 5D91 | 216 | 586 | 117 | 0.200 | 0.168 | 117E91 | 334 | 789 | 27 | 0.034 | 0.068 |
| 8D91 | 216 | 679 | 59 | 0.086 | 0.168 | 123E91 | 216 | 865 | 43 | 0.050 | 0.068 |
| 10D91 | 322 | 462 | 58 | 0.126 | 0.168 | 123E91 | 322 | 291 | 15 | 0.052 | 0.068 |
| 11D91 | 322 | 388 | 20 | 0.052 | 0.168 | 124E91 | 322 | 524 | 53 | 0.101 | 0.068 |
| 11D91 | 324 | 299 | 60 | 0.262 | 0.168 | 127E91 | 300 | 1010 | 67 | 0.066 | 0.068 |
| 12D91 | 354 | 322 | 28 | 0.087 | 0.168 | 128E91 | 323 | 673 | 43 | 0.064 | 0.068 |
| 15D91 | 352 | 341 | 71 | 0.208 | 0.168 | 129E91 | 216 | 274 | 8 | 0.029 | 0.068 |
| 16D91 | 353 | 368 | 43 | 0.117 | 0.168 | 130E91 | 919L | 714 | 82 | 0.115 | 0.068 |
| 17D91 | 344 | 1200 | 69 | 0.058 | 0.168 | JUNE | | | | | |
| 18D91 | 216 | 814 | 144 | 0.177 | 0.168 | 13F91 | 216 | 479 | 22 | 0.046 | 0.074 |
| 18D91 | 322 | 245 | 33 | 0.135 | 0.168 | 14F91 | 919R | 283 | 46 | 0.163 | 0.074 |
| 22D91 | 322 | 746 | 86 | 0.115 | 0.168 | 15F91 | 322 | 603 | 18 | 0.030 | 0.074 |
| 22D91 | 919R | 152 | 27 | 0.178 | 0.168 | 110F91 | 322 | 417 | 16 | 0.038 | 0.074 |
| 24D91 | 322 | 498 | 83 | 0.167 | 0.168 | 111F91 | 322 | 513 | 0 | 0 | 0.074 |
| 24D91 | 216 | 693 | 199 | 0.287 | 0.168 | 112F91 | 322 | 245 | 12 | 0.049 | 0.074 |
| 25D91 | 323 | 780 | 48 | 0.062 | 0.168 | 118F91 | 216 | 510 | 38 | 0.075 | 0.074 |
| 25D91 | 339 | 408 | 151 | 0.370 | 0.168 | 114E91 | 919R | 291 | 33 | 0.113 | 0.074 |
| 26D91 | 300 | 551 | 44 | 0.080 | 0.168 | 117F91 | 220/4 | 600 | 29 | 0.049 | 0.074 |
| 29D91 | 216 | 218 | 19 | 0.087 | 0.168 | 118F91 | 919L | 381 | 47 | 0.123 | 0.074 |
| MAY | | | | | | 118F91 | 919R | 215 | 31 | 0.144 | 0.074 |
| 3E91 | 216 | 168 | 27 | 0.161 | 0.068 | 119F91 | 507 | 557 | 73 | 0.0131 | 0.074 |
| 7E91 | 322 | 999 | 81 | 0.081 | 0.068 | 120F91 | 216 | 559 | 27 | 0.043 | 0.074 |
| 8E91 | 919R | 485 | 24 | 0.049 | 0.068 | 121F91 | 334 | 438 | 11 | 0.025 | 0.074 |
| 10E91 | 322 | 238 | 12 | 0.050 | 0.068 | | | | | | |
| 10E91 | 323 | 187 | 27 | 0.144 | 0.068 | | | | | | |

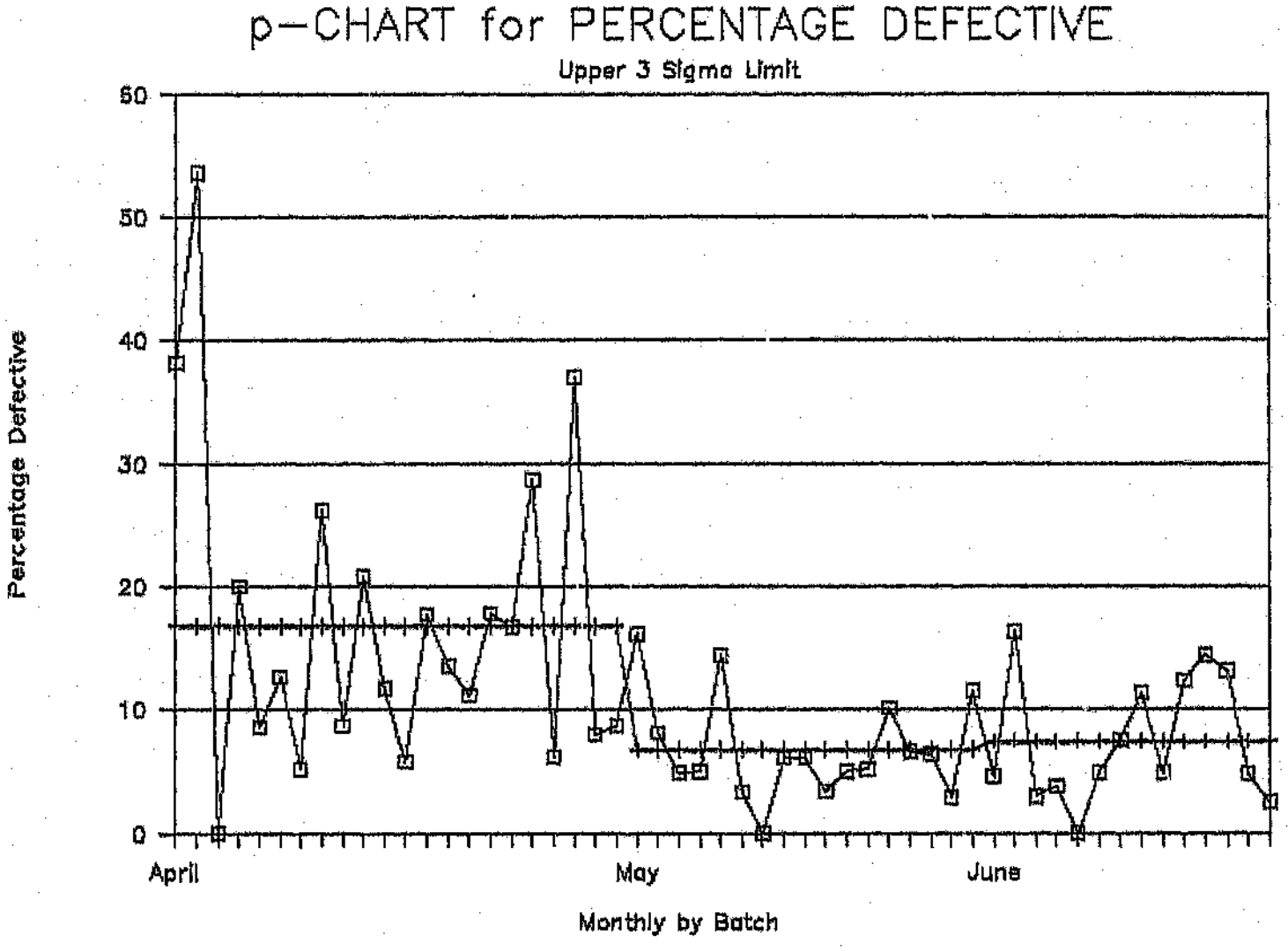

p—CHART for PERCENTAGE DEFECTIVE
Upper 3 Sigma Limit
Percentage Defective
60
50
40
30
20
10
0
April
May
June
Monthly by Batch

Fig. 8.4

# 9 CONCLUSION

## 9.1 SABS 0157 Part 2

The value of SABS 0157 Part 2 is in the structuring of the quality management system. To date the major task of creating the basic operating procedures for the quality manual have been completed which implies that a quality management system is functioning. This is indeed the case albeit due to senior management involvement.

In considering the typical life cycle of a foundry it is obvious that during the early stages i.e. changing from the "project" to a "production" phase there are many conflicting interests. Project orientation is on "fine tuning" the process while that of production (and the investors) want high output yield. It is here that quality management systems played a high profile in resolving these issues - with the emphasis on "do it right - first time".

With regard to the quality manual, it was necessary to make several addendums to the basic SABS requirements i.e. expanding the statistical process control section; including human resources section; defining policy procedure policy statements; stating company safety policy and defining quality control

costs. These addendums proved to be satisfactory to all the motor manufacturers.

## 9.2 QUALITY AUDITS

Quality Audits were carried out in the ation the project.

First was an in-house audit lead by the Quality Manager of Hubco, on of our sister companies. This was carried out two weeks prior to the BMW audit. A ority list, together with a plan of action to ensure timeous implementation was drawn up.

Second was the preliminary BMW audit conducted form 22nd to the 24th May, which is a month earlier than originally anticipated. This audit took three days to complete and was carried out in accordance with the BMW QSK-01 format. Most significant deficiency pointed out was the lack of control over specifications in that there was no apparent link between a drawing change level and the recall system for specification amendments. Also noted were eighteen minor items which need to be addressed. Part of QSK-01 is an action plan programme which will remedy these, and other, short comings before the next official audit in October this year. Points awarded for this audit were midway between

B1 and B2 rating and the action plan is geared to achieving an A2 rating in October. Senior management, needless to say, are very pleased with the results achieved so far.

The third and last audit was carried out by Nissan on the 28th May. The original plan was that this audit would take place before the BMW audit. Many of the points noted from this audit were similar to the previous audits. The company was given a "B" rating with the opportunity of another audit in September, by which time sufficient work could have been done to merit an "A" rating.

Both customers were satisfied with the quality progress made and noted that it was unusual to achieve such favorable ratings in such a short period.

## 9.3 DESIGN OF EXPERIMENT

The investigation into the physical characteristics of green sand with variation in sand ingredients proved to be of great value. It also showed that much more attention should be paid to sand physical haracteristics, that much more of this type of investigation is needed.

The experiment showed how critical both water and

bentonite are on the physical makeup. It is envisaged that a new set of experiments which will examine effects of residual fines and bentonite on the mouldability of green sand will be carried out. Winter has brought on a new problem of temperature. Relationship between moisture, temperature, compactibility and flowability also needs to be examined.

## 9.4 CAPABILITY STUDY

The production of high carbon components on the Kunkel Wagner is very dubious. The process requirements and the process capability are too close, so that any marginal production variation results in unacceptable product being produced.

It appears that this type of component is best made on the Disa Matic moulding machine which allows for easier control of in mould cooling down temperature control, which seems to be the element which is lacking on the Kunkel Wagner process.

## 9.5 PROCESS CONTROL

This is the most important visible element in quality systems. Process control sheets integrate process capability with process control and provides the process operator with immediate feed back on the process performance. Control sheets introduced generally proved to be very successful and also highlight the necessity to keep all the process elements under control. In the metal pouring procedure this has lead to very significant improvement in the percentage scrap components produced.

## 9.6 LESSONS LEARNT

The task of implementing quality systems is never completed. Updating and writing new procedures is an ongoing task, and as the quality system itself strives for continual improvement the volume of this task reflect it's effusiveness.

Much of what has been achieved has been as a result of simply applying rudimentary text book techniques. Further improvements will stem from a more general understanding of quality principals by all echelons of employees. This applies particularly to highly operator

intensive environments. Correspondingly, the more sophisticated the quality system, the greater the probability that entrophy will take over.

For this reason all the statistical analysis has been centralised in the systems department. Results have to be fed back quickly in order to be effective. Generally quality progress reports have been well accepted and therefore, qualifies the effeciveness of "visibility management" techniques.

The Quality Manual is in itself a fairly mundane collection of documents. Few managers have any burning desire to read, let alone, study all the set out procedures and instructions. A much more effective means of communications are the "Process Specification Sheets", which summarise the pertinent operations and points out critical requirements and settings - often diagrammatically.

The overall effectiveness in the quality system is in the measurement of scrap components. Rework is confined mainly to esthetic characteristics and all other defects, like perosity, inclusions, gas etc., are scrapped. The problem in scrap control is to avoid polarisation between "inspection" and "production" departments. this , the author, believes has been overcome with the introduction of the Quality Management Team (QMT). It is their ultimate task to set

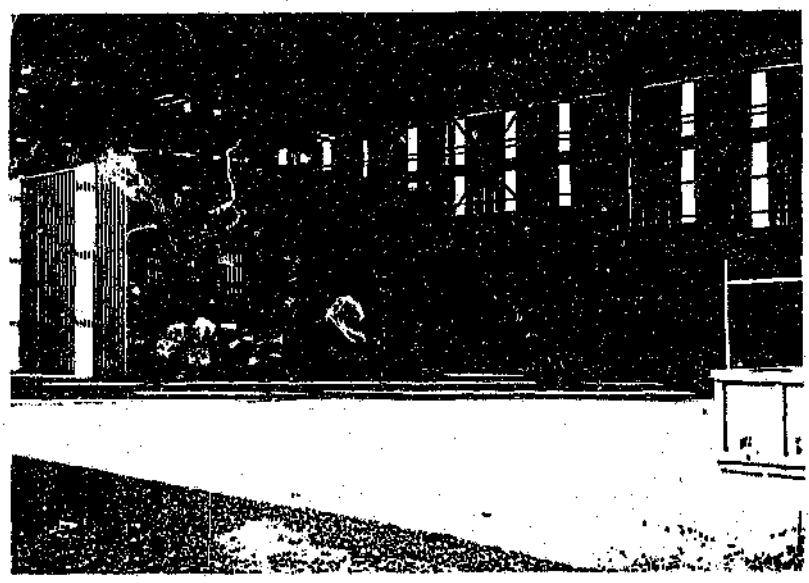
the physical inspection standards and to maintain these standards. After an initial period of uncertainty, the team settled down to mutually beneficial compromises.

## 9.7 FUTURE IMPROVEMENTS

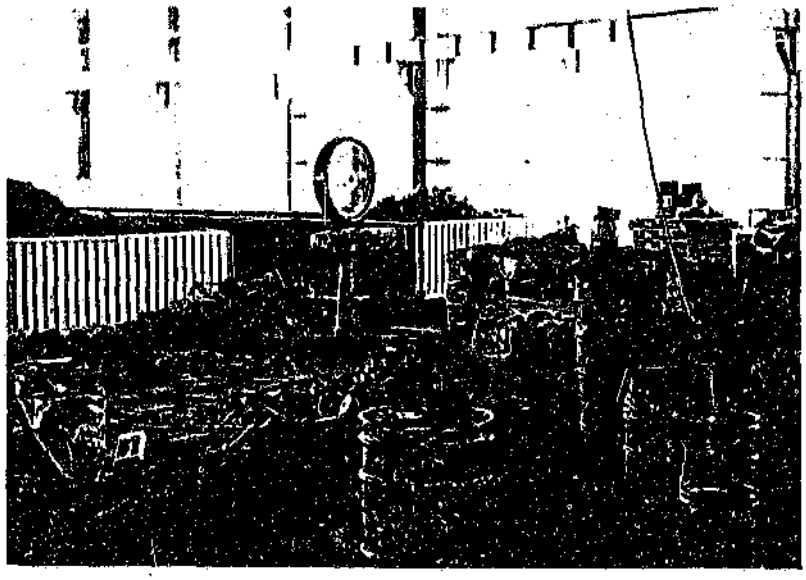
Auto Industrial Foundry should use the Quality System as a model for developing all systems throughout the group. Because Quality Management is not a closed system, it interacts with every other activity in the manufacturing environment - and certainly the whole group should be viewed as a Manufacturing System. This open approach will enhance the prospects of the whole group in it's expansion programme.

APPENDIX A

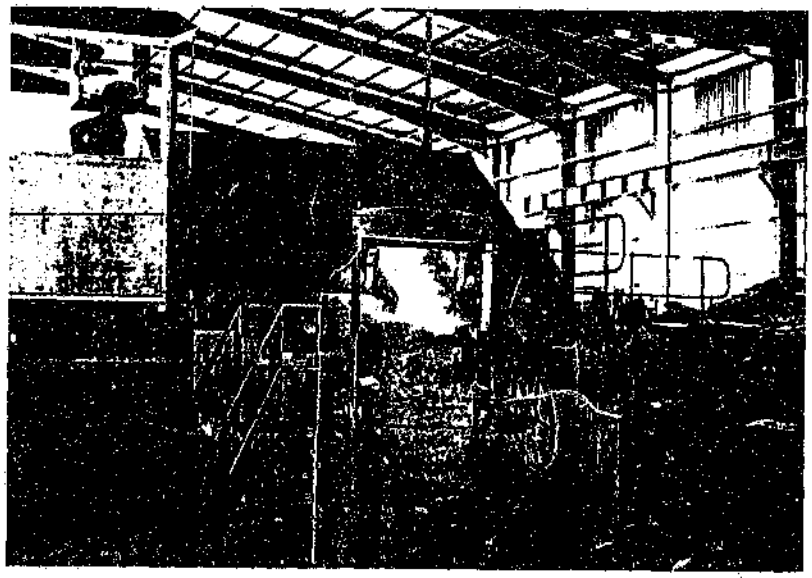
Photograph 1 - Quality starts with carefully graded scrap.



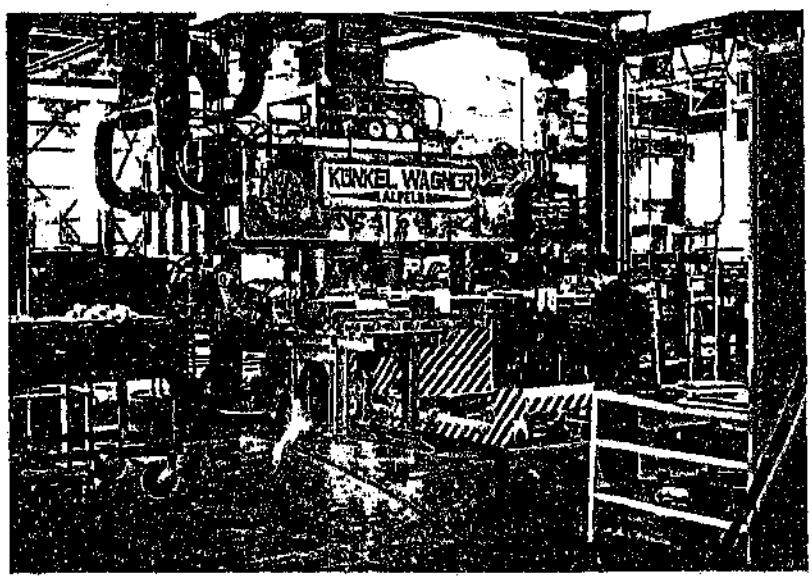
Photograph 2 - Raw materials being carefully weighed before charging into the furnace.



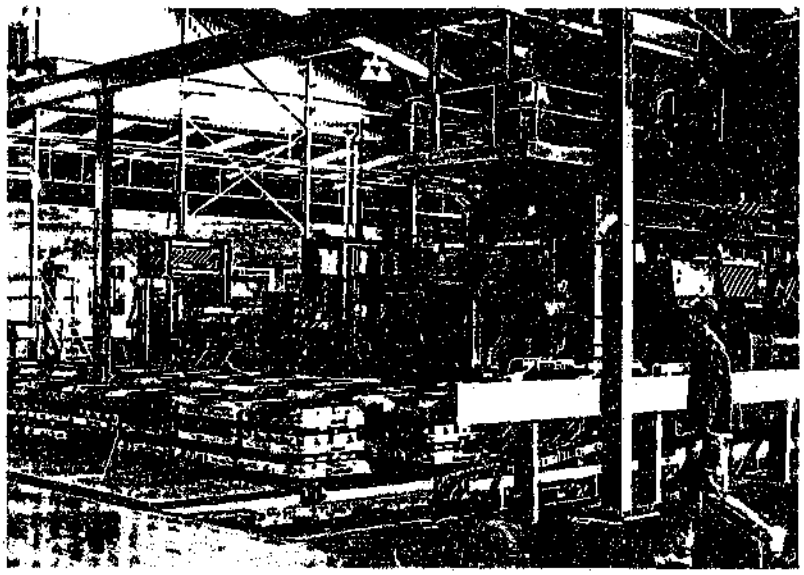
Photograph 3 - Metal being tranfered from melting to holding furnace.



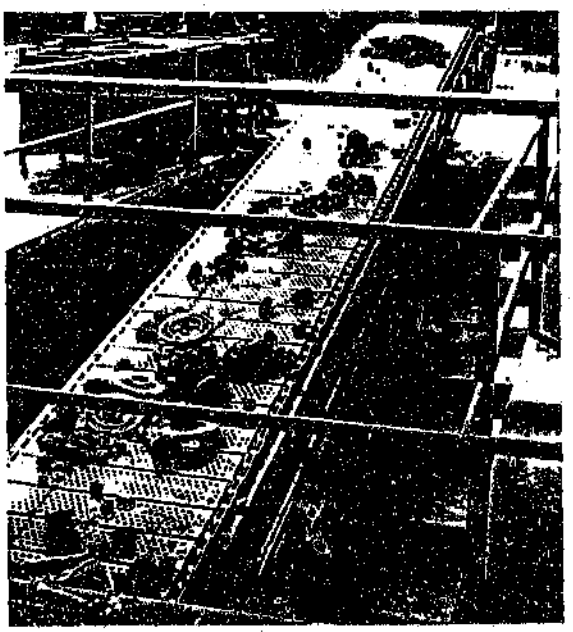
Photograph 4 - Kunkel Wagner automatic moulding line



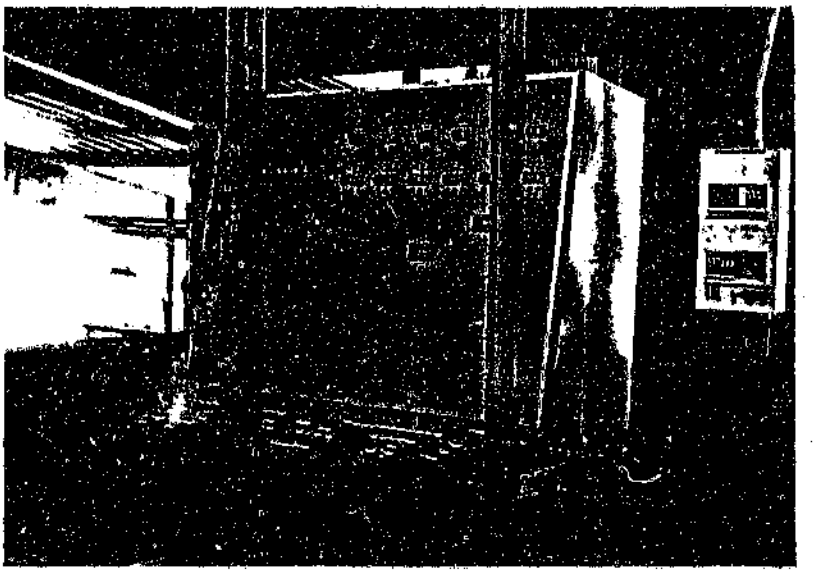
Photograph 5 - Pouring and cooling lanes for the Kunkel Wagner.



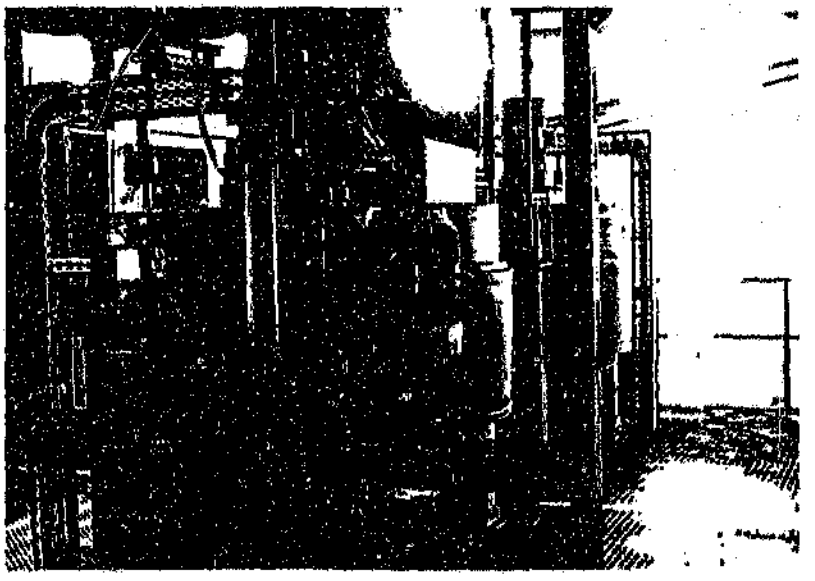
Photograph 6 - Clean castings being taken out of the 'shake-out'



Photograph 7 - Control panel for the automatic green sand plant



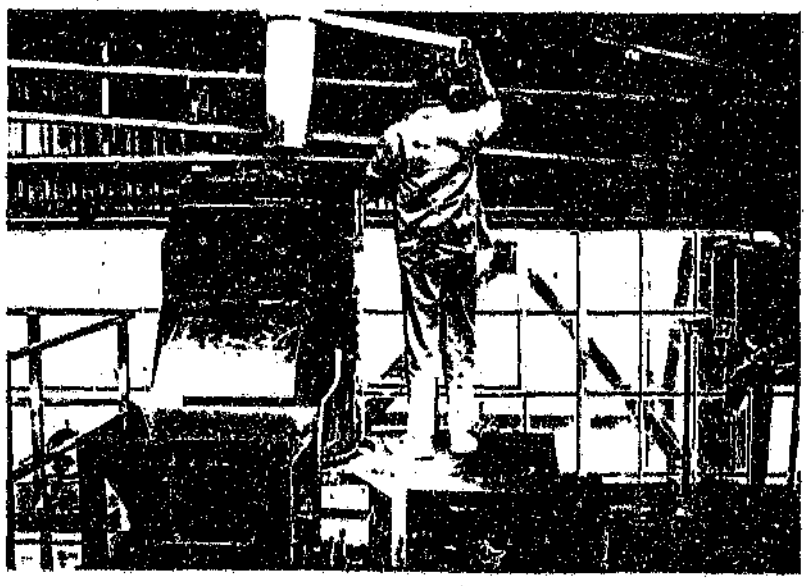
Photograph 8 - Mixer mill. Materials are gravity fed from the silos



Photograph 9 - View of the green sand plant. Sand is taken out on conveyors.



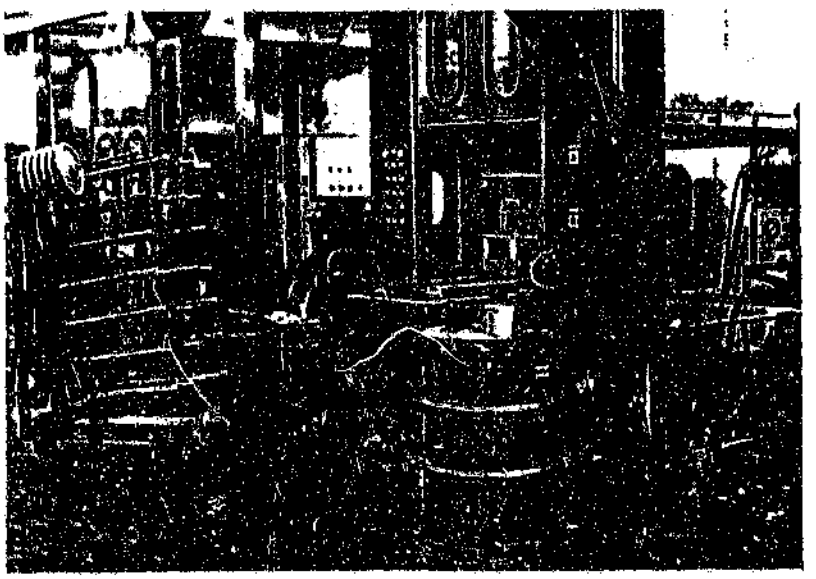
Photograph 10 - Mixing core sand. Sand is gravity fed into the mixer.



Photograph 11 - Core moulding machine - after automatic cycle is completed.



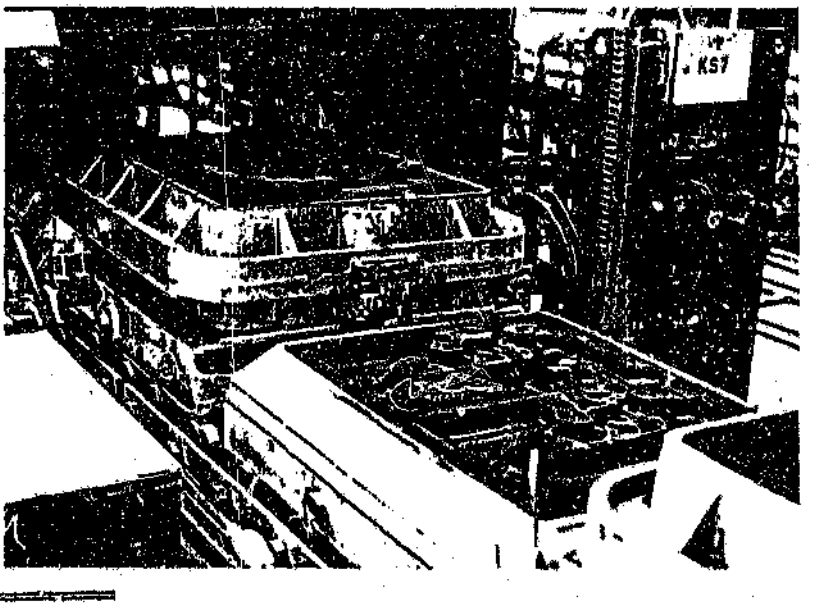
Photograph 12 - Removing core and resetting the automatic cycle.



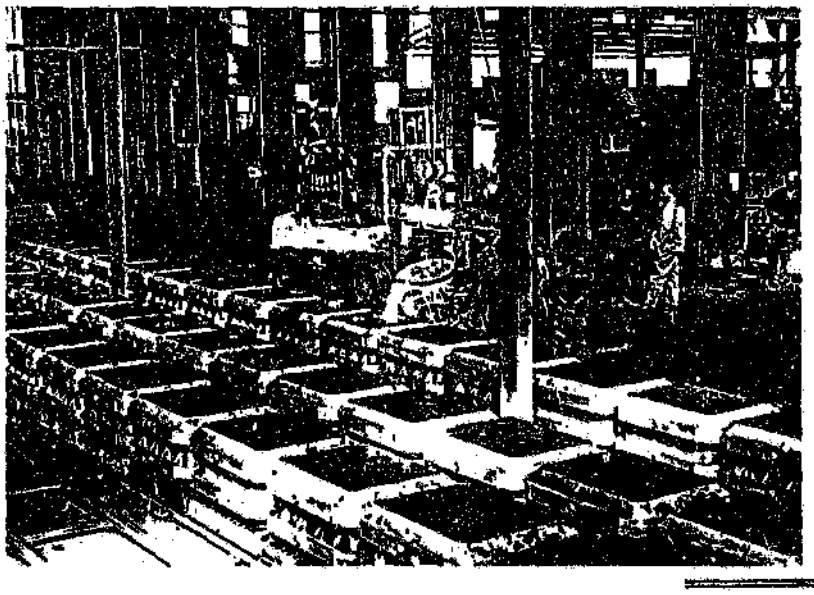
Photograph 13 - Inoculating a pouring ladle - before delivery to the line.



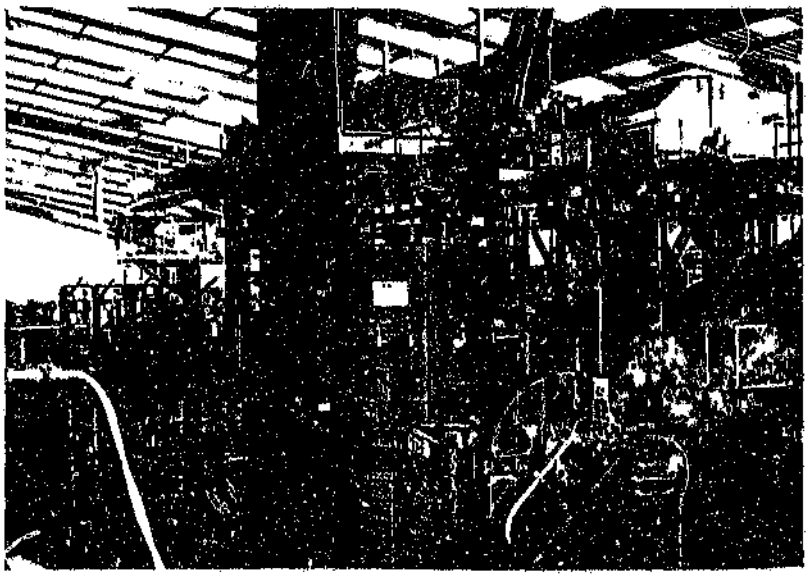
Photograph 14 - Complete mould ready for closing.



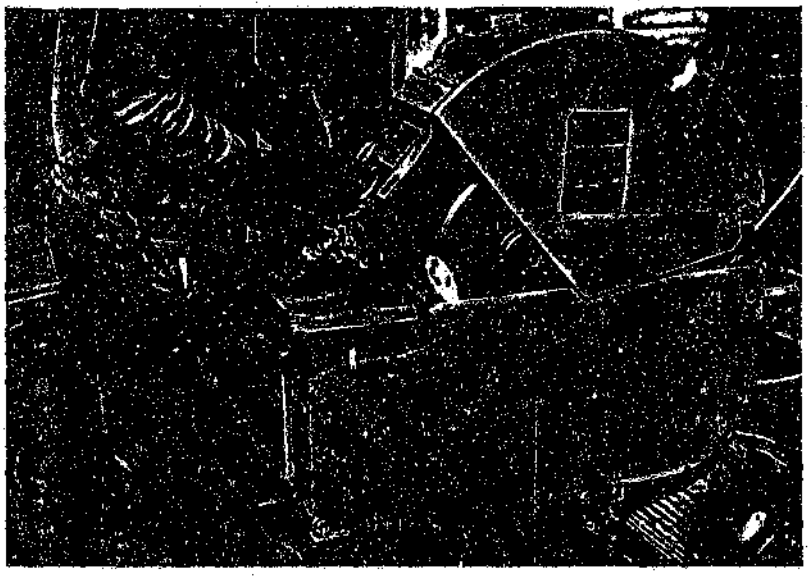
Photograph 15 - Pouring metal into mould on the pouring lane.



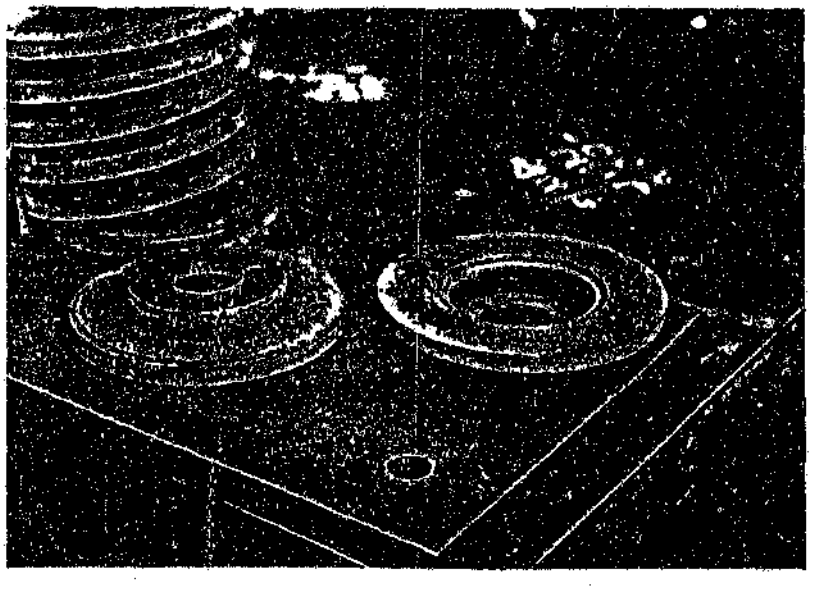
Photograph 16 - Shot blast machine for cleaning sand off castings.



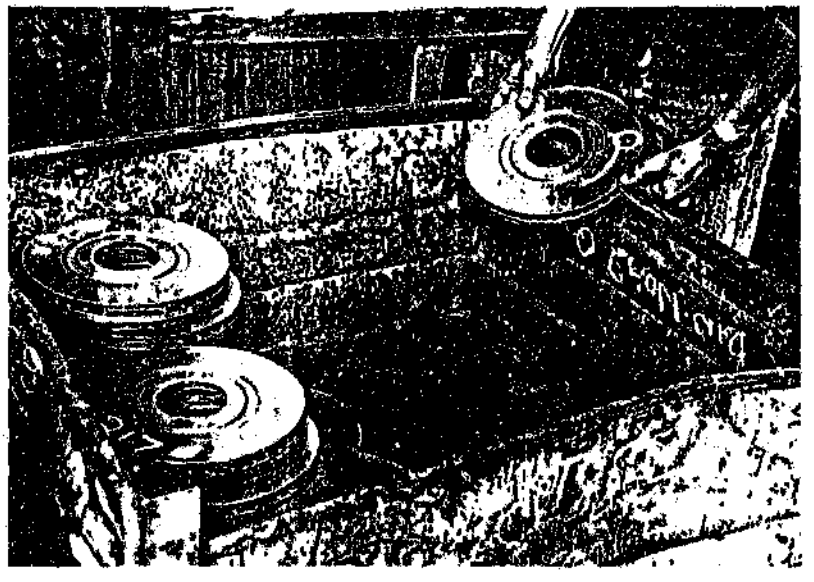
Photograph 17 - Removing flash and feeders by grinding.



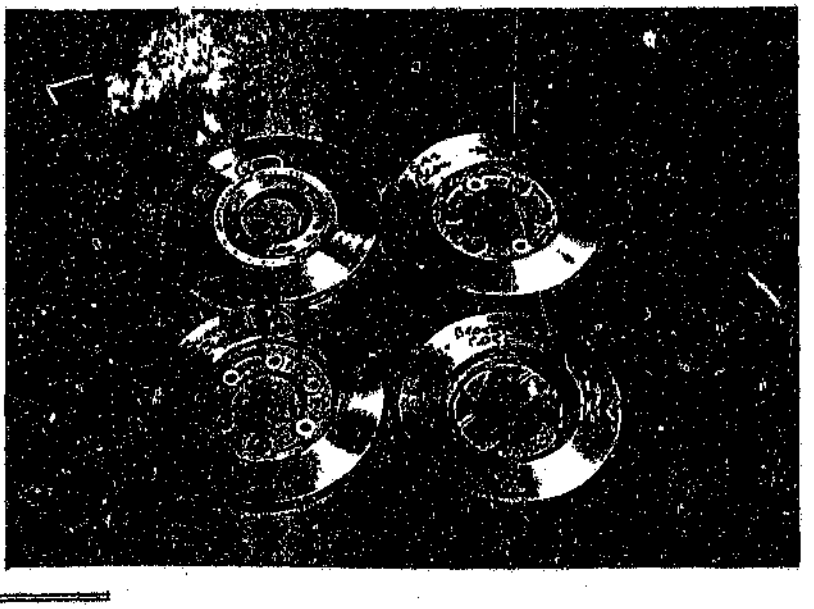
Photograph 18 - Castings ready for inspection



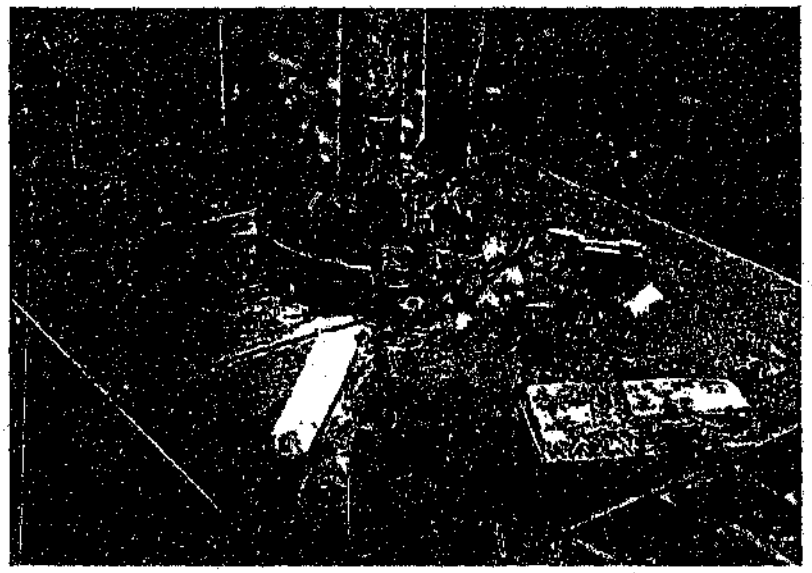
Photograph 19 - Carefully visual inspection - marking all defects.



Photograph 20 - Classifing reject castings for statistical analysis.



Photograph 21 - Sectioning castings to examine core metallurgy.



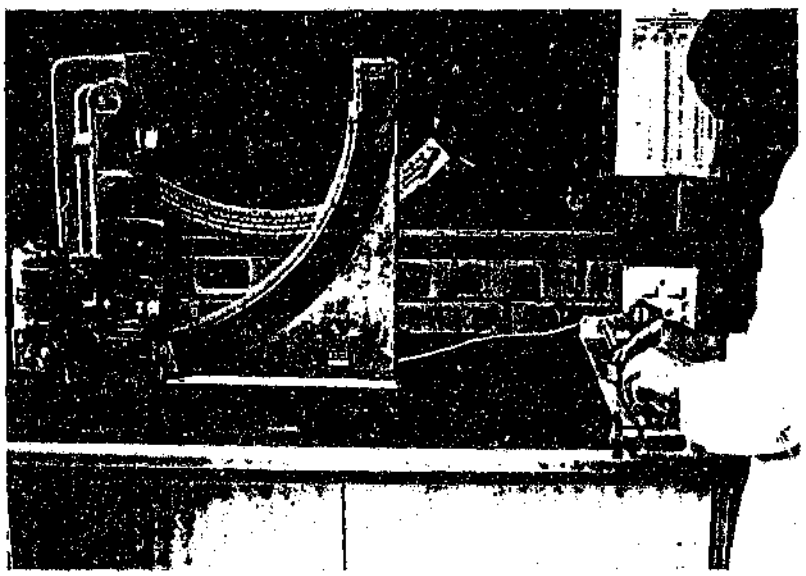
Photograph 22 - Detail of green sand half mould



Photograph 23 - Laboratory equipment for determining sand characteristics.



Photograph 24 - Equipment used for measuring quality of sand.



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