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TITLE

IMPLEMENTING QUALITY SYSTEMS

IN A FOUNDRY

by

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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, una.ded work. It is being submitted for the Degree of Mar.er of Science in Engineering in the Universit, of the Witwatersrand, Johannesburg. It has not br.en 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 o. 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 MY PARENTS

HENRY and GRACE BOSCH

ACKNOWLEDGMENTS

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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".

QUALITY PERCEPTION
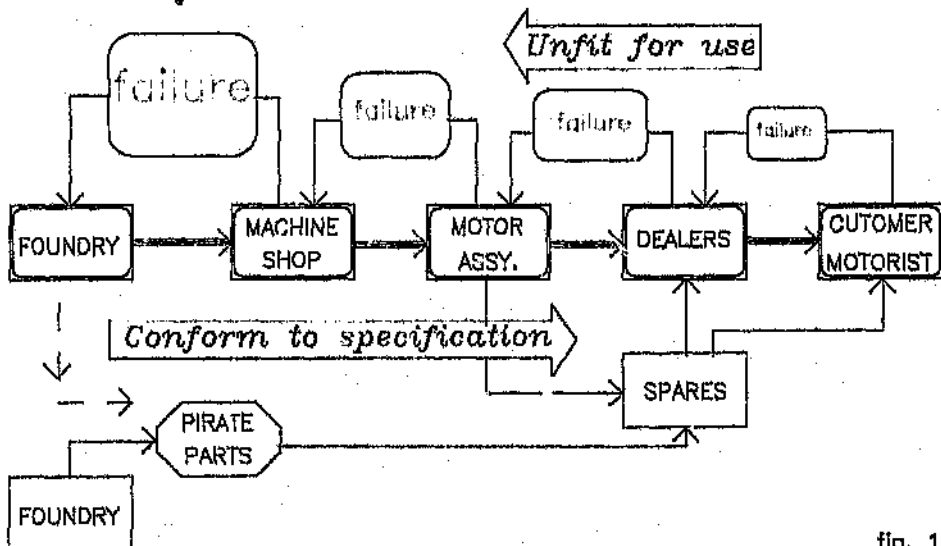
fig. 1.1

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

Melting   Product   Sand

SALES CONTRACTS

RAW MATERIALS
— Vendor Certificate
— Visual Inspection
— Analysis

PLANNING
— Schedules
— Materials

RAW MATERIALS
— Vendor Cert.
— Visual Insp.
— Lab Tests

MELTING
— Charge Mass
(I) — Temperature
(T) — Chemical Analysis
— Timing

PATTERN STORE
— Wear Check
— Defect Check
— Identification
— Cleanliness

MIXING
(I) — Tests
— Visual Insp.

TREATMENT
— Additions
— Delivery
(I) — Metallurgical Tests

MOULDING
— Core Setting
— Mould Quality
— Venting
(I) — Innoculating
— Repeatibility

POURING
(I) — Temperature
— Cleanliness
— Time (rate)

PIGS
— Identification
— Cleanliness

SHAKE OUT
— Time Delay

USED SAND
— Seperation
— Cooling

RUNNERS
— Identification
— Cleanliness

FETTLING & FINISHING
— Surface Finish
— Nett Shape

METALLURGICAL
(I) — Tests
— Release
(I) — Hardness

INSPECTION
(I) — Visual Defects
(I) — Dimensional
(I) — Tests

SCRAP
— Identification
— Cleanliness
(I) — Analysis

DELIVERY
— Certification

(I) In-Process Inspection

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 9 years - although "safety critical" components must be kept for 10 years.

However, SABS 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
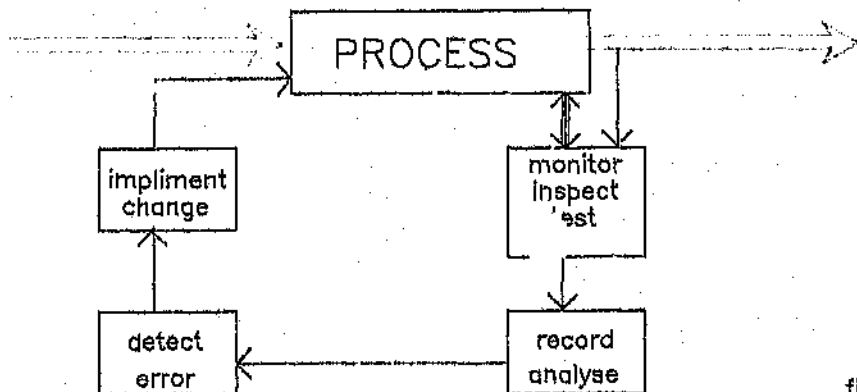
fig 3.1

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.

THE REDUCTIONIST APPROACH TO PROBLEM SOLVING
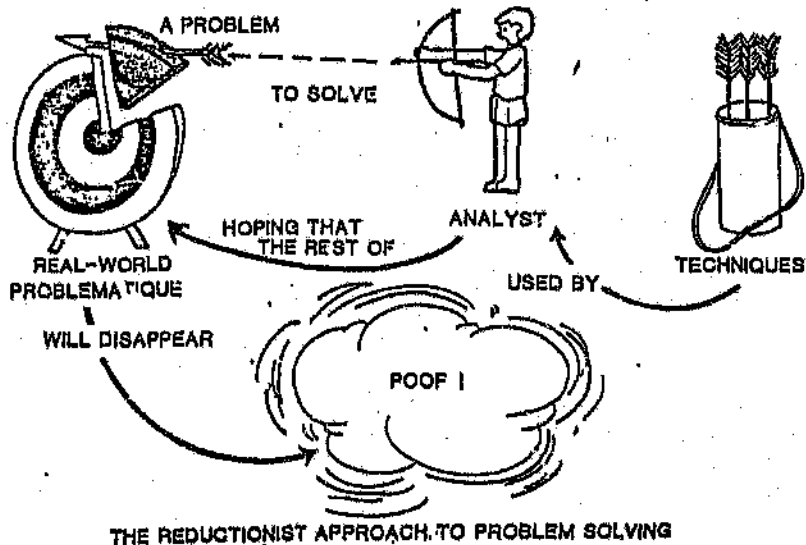
fig 3.2

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 manufactures 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 manufactures 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
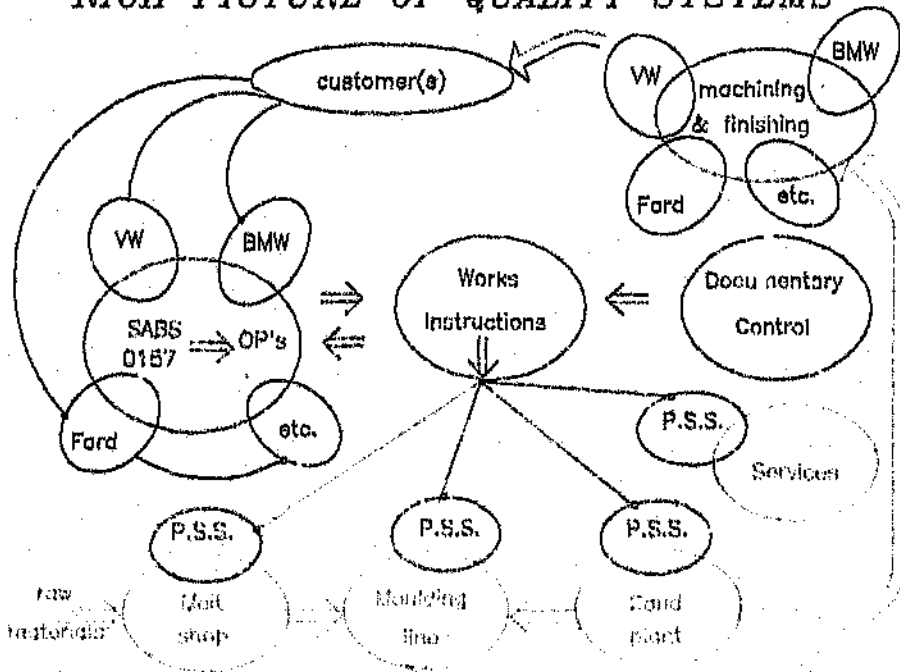
P.S.S. = Process Specification Sheet   fig. 3.3

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(90)

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   (30)

                                         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.

3.5 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 not 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.
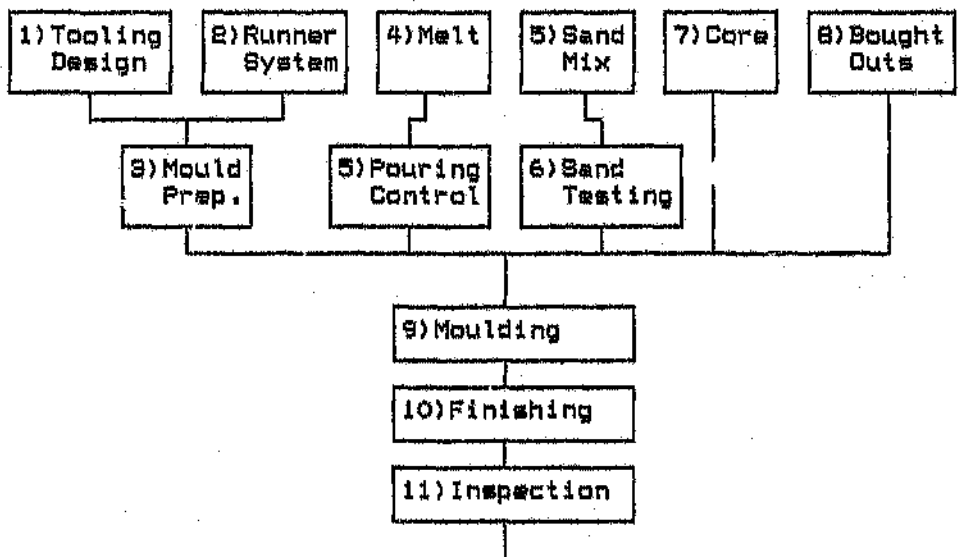
4.2 FMEA TEAM

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

```
┌──────────┐ ┌──────────┐ ┌────────┐ ┌────────┐ ┌────────┐   ┌──────────┐
│1)Tooling │ │2)Runner  │ │4)Melt  │ │5)Sand  │ │7)Core  │   │8)Bought  │
│Design    │ │System    │ │        │ │Mix     │ │        │   │Outs      │
└──────────┘ └──────────┘ └────────┘ └────────┘ └────────┘   └──────────┘

       ┌──────────┐      ┌──────────┐ ┌────────┐
       │3)Mould   │      │5)Pouring │ │6)Sand  │
       │Prep.     │      │Control   │ │Testing │
       └──────────┘      └──────────┘ └────────┘

                     ┌──────────────┐
                     │9)Moulding    │
                     └──────────────┘

                     ┌──────────────┐
                     │10)Finishing  │
                     └──────────────┘

                     ┌──────────────┐
                     │11)Inspection │
                     └──────────────┘
```

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

Potential Failure (Actual)	Potential Consequences for the Customer (Effect)	Potential Reasons for the Failure (Cause)	D	Current Status				Recommend Corrective Measures	Responsibility	Improved Status		
				Existing Control Measures			Risk Priority Factor			Measures Taken		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	Machine settings
Worn Tooling	Inaccurate gauging
Wrong metallurgy	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 3
MODERATE failure which causes the customer dissatisfaction. Customer is made uncomfortable or is annoyed by the failure.	4 5 6
HIGH degree of customer dissatisfaction due to the nature of the fault.	7 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	2	1/5 000
is dispatched with the defect	3	1/2 000
The defect is obvious	4	1/1 000
	5	1/500
MODERATE. Defect is easily	6	1/200
identified	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 $\underline{\diagdown S \diagup}$
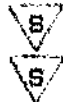
Hardness 160 - 190 BHN $\underline{\diagdown S \diagup}$

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
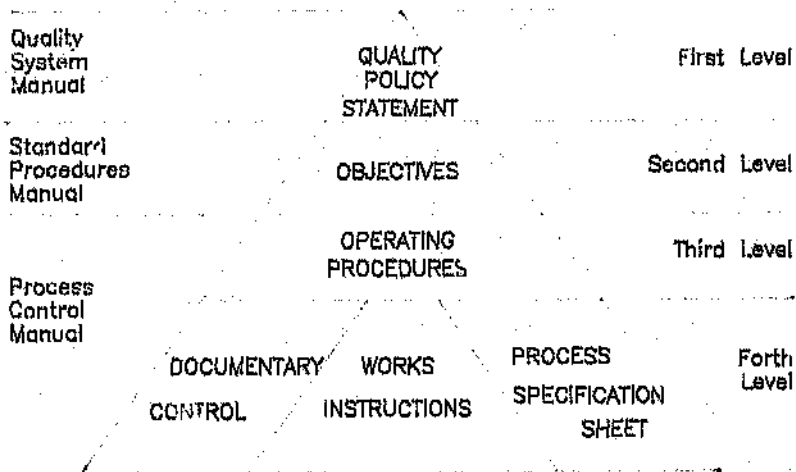* Standard Operating Procedures
* Works Instructions

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

Quality System Manual	QUALITY POLICY STATEMENT	First Level
Standard Procedures Manual	OBJECTIVES	Second Level
	OPERATING PROCEDURES	Third Level
Process Control Manual		
DOCUMENTARY CONTROL	WORKS INSTRUCTIONS	PROCESS SPECIFICATION SHEET	Forth Level

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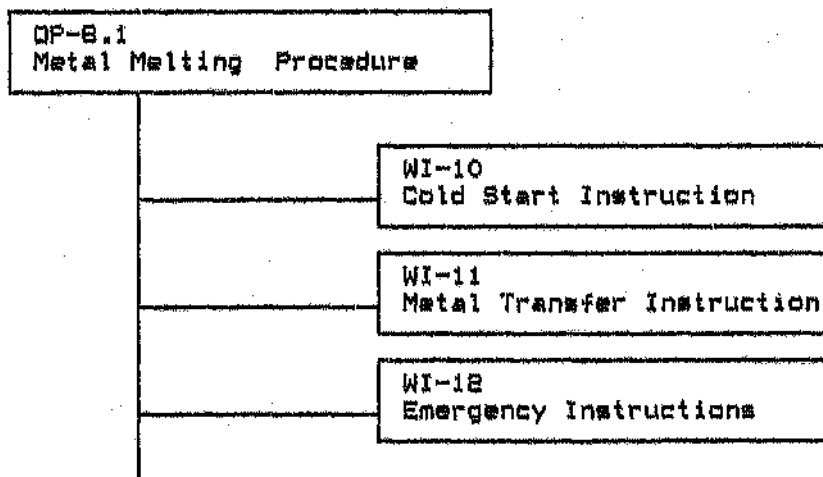
To achieve this the following programme has to be followed:-

```
                        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

```
┌─────────────────────────┐
│ QP-8.1                  │
│ Metal Melting  Procedure│
└─────────────────────────┘
    │
    │         ┌──────────────────────────────┐
    ├─────────│ WI-10                        │
    │         │ Cold Start Instruction       │
    │         └──────────────────────────────┘
    │         ┌──────────────────────────────┐
    ├─────────│ WI-11                        │
    │         │ Metal Transfer Instruction   │
    │         └──────────────────────────────┘
    │         ┌──────────────────────────────┐
    ├─────────│ WI-12                        │
    │         │ Emergency Instructions       │
    │         └──────────────────────────────┘
    │
```

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. 5.8. Exact details of production qualities, delays, component changes, etc. are recorded.

Part Description:

Make: | **Model:**

Cstmr Dwg No:

(1) Material Specifications:— | **(3) Cores**

Machine Settings:—

Cstmr Spec: **AIF Spec:** | Gas Pressure P1: P2: P3:

Chemical Analysis | Timers:— Blow Purge

C	Si	P	S	Mn										
														max
														min

Exhaust Gas

Dip:

Max Furnace Temperature:

Cast Temperature: Max Min | **Production Rate:** Components / Hour

Ladle Treatments

(2) Casting Methods | **(4) Finishing**

Machine: | Shot Blast

Core: | Band Saw

Strainer: Mould Innoculants:

No. Components / Mould: | Fettle

Machine Settings:—

Sand Timers — Top Box Sec. | **(5) First Off Inspection**

Bottom Box Sec. | Visual Inspection:

Clamping Pressure:Top Bar

Clamping Pressure: Bottom Bar | Hardness:

Maximum Cooling Time: Min

Minimum Cooling Time: Min | Metallurgical Inspection:

Production Rate: Components / Hour | Dimensional Check:

Notes | **Notes**

Drawing – Sketch

Revision Dates							
Revision Level:							
Factory Manager							
Systems							
Metallurgy							
Development							

Approved by

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.
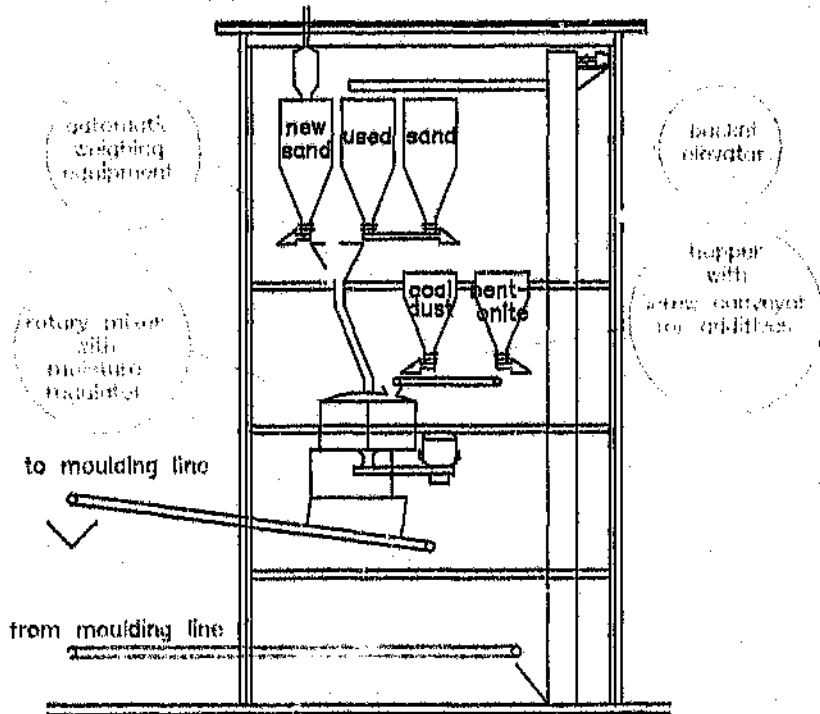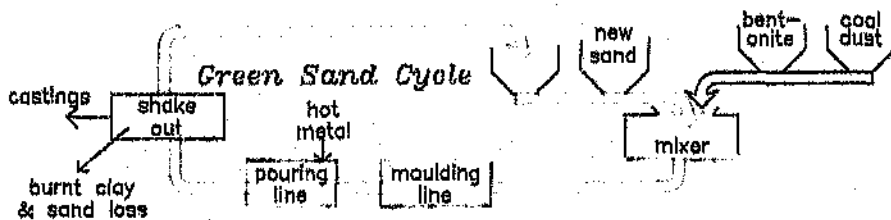
MOULDING SAND PREPERATION

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

Green Sand Cycle

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 cor¹ 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 contolable 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+bc+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	3,0%	7,0%

fig. 6.3
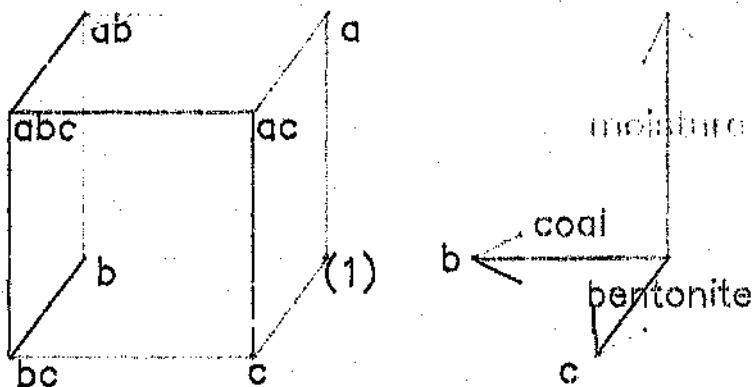
6.3 RESULTS & ANALYSIS

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 18 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
18	1	abc	44	44	30	26	33	28.5	2.1	1.5	45	34

Note: the first three header columns span as Random Run | Std. Ord. | the test block label; the numbered sub-columns (1, 2) belong to Compact., Shear, Crush, Tensile and Hardness. The table cells above place the run/std/label values in the first three columns, then the paired measurements.

Table 6.3 shows the me'iod 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 6.9 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)			79	195	378	667						
a			116	183	289	171	1817	A	1	1817	367	+++++
b			72	151	76	−25	38	B	1	38	8	+++++
ab			111	138	95	−17	17	AB	1	17	3	
c			47	37	−12	−90	601	C	1	601	101	+++++
ac			104	39	−13	19	21	AC	1	21	4	
bc			50	57	2	−1	0	BC	1	0	0	
abc			88	38	−19	−21	26	ABC	1	26	5	
TOTALS	340	327	667			ERROR	40		3	8		
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)			29	69	129	306					
a			40	60	177	82	420	A	1	420	47 +++++
b			26	92	19	−18	16	B	1	16	2
ab			34	85	63	−12	9	AB	1	9	1
c			28	11	−9	48	144	C	1	144	16 +++++
ac			64	8	−7	44	121	AC	1	121	14 +++++
bc			29	36	−3	2	0	BC	1	0	0
abc			56	27	−9	−6	2	ABC	1	2	0
TOTALS	149	187	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 & INREACTION	DoF	MEAN SQ	f
(1)			42	83	159	361					
a			41	76	202	59	214	A	1	214	24 +++++
b			35	109	5	−24	36	B	1	36	4
ab			41	93	54	15	13	AB	1	13	1
c			43	−1	−7	43	113	C	1	113	13 +++++
ac			56	6	−17	49	147	AC	1	147	17 +++++
bc			31	23	7	−10	5	BC	1	6	1
abc			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)			2	4	6	16					
a			2	2	10	6	2	A	1	2	17 +++++
b			1	8	0	−2	0	B	1	0	2
ab			1	8	6	−1	0	AB	1	0	0
c			1	1	−2	4	1	C	1	1	8 +++++
ac			4	−0	−1	5	1	AC	1	1	12 +++++
bc			1	3	−1	1	0	BC	1	0	1
abc			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)			77	162	326	612					
a			85	164	286	76	360	A	1	360	30 +++++
b			78	150	16	−12	9	B	1	9	1
ab			86	136	62	18	20	AB	1	20	2
c			55	8	2	40	100	C	1	100	8 +++++
ac			95	8	−14	46	132	AC	1	132	10 +++++
bc			57	40	0	−16	16	BC	1	16	1
abc			79	22	−18	−18	20	ABC	1	20	2
TOTALS	315	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 techn ue 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 352 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

HISTOBARS

fig 7.2

X CHART — 8 SIGMA LIMITS
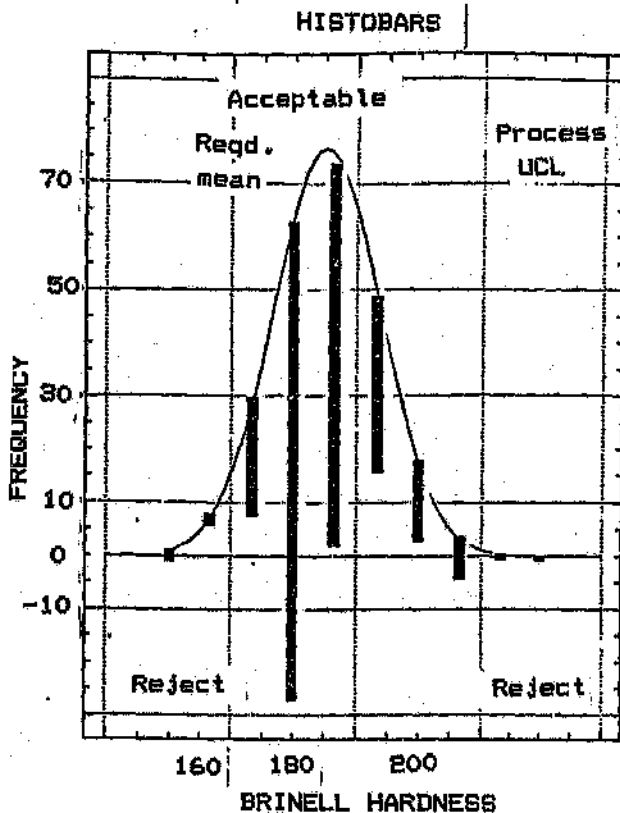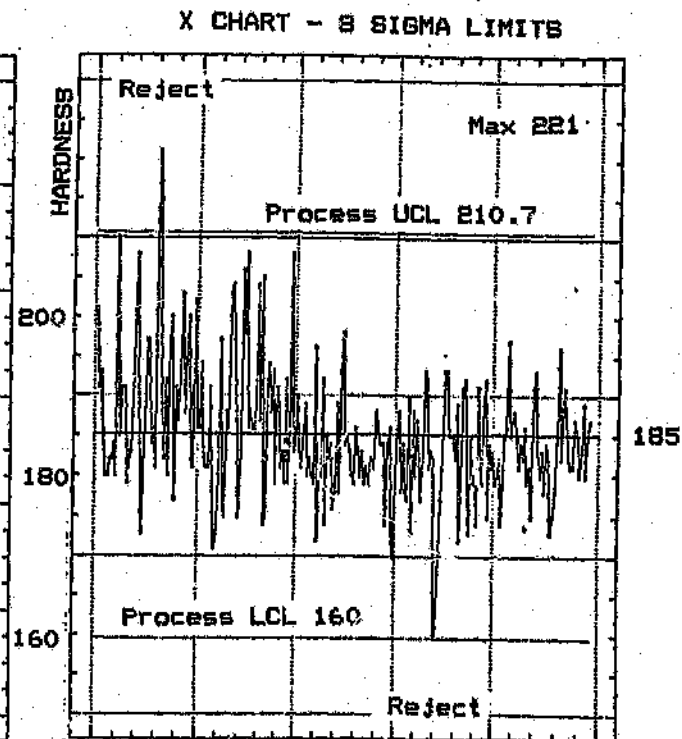
table 7.1 Statistical Analysis

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	2.01409
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 analysis 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

2. Analysis of Variance

Source	Sum of Squares	DoF	Mean Square	F-Ratio	Prob.
Model	3054.6573	1	3054.6573	105.221	0
Error	580.6154	20	29.0308		
Total(Corr)	3635.2727	21			

Correlation Coefficient = -0.9167

Std. Error of Estimate = 5.3880

R-squared = 84.09 percent

3. Graph — Casting Cooling Characteristic

fig 7.1

MOULD KNOCK-OUT TIME IN MINUTES
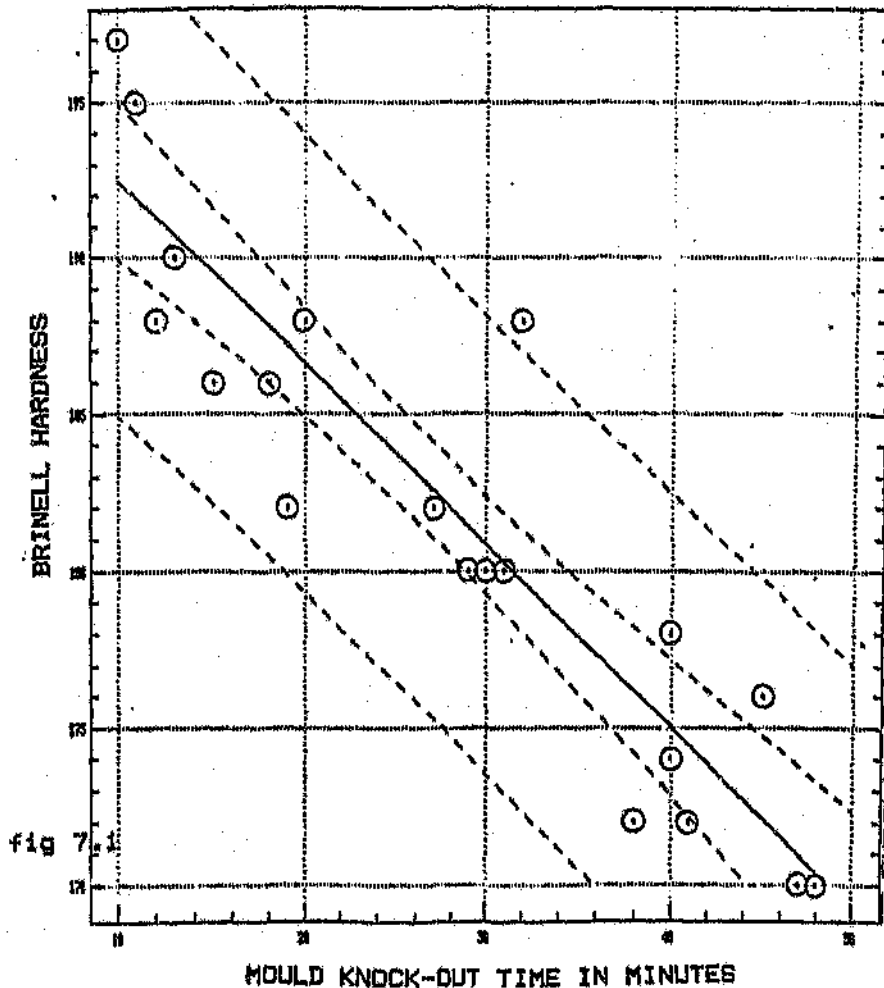
From this it can be seen that there is reasonable correlation between hardness and knock-out time. Solification of the metal in the mould is completed after about 10 minutes, with pouring temperatures of 1400 degrees centigrade. However, at this stage the metal is likely to be damaged (distorted) in 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
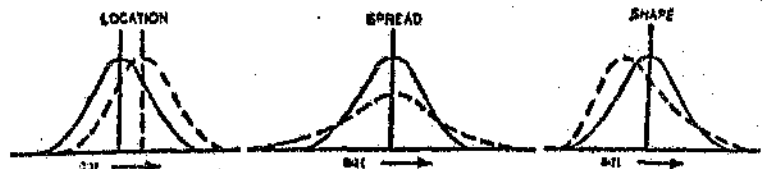
IF ONLY COMMON CAUSES OF VARI-
ATION ARE PRESENT, THE OUTPUT
OF A PROCESS FORMS A DISTRIBU-
TION THAT IS STABLE OVER TIME
AND IS PREDICTABLE.
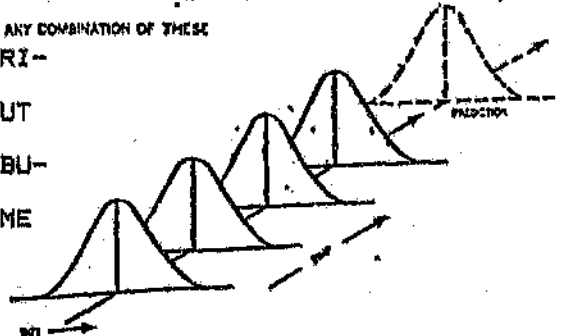
IF SPECIAL CAUSES OF VARIATION
ARE PRESENT, THE PROCESS OUTPUT
IS NOT STABLE OVER TIME AND IS
NOT PREDICTABLE.
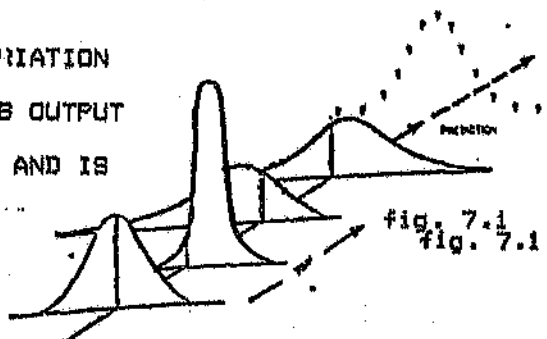
fig. 7.1
fig. 7.1

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.

```
                  +-----------------------------+
                  |   Foundry Process Control   |
                  +-----------------------------+
          +-----------------+-----------------+
 +----------------+  +----------------+  +----------------+
 | Metallurgical  |  |  Production    |  |  Sand          |
 | Control        |  |  Process       |  |  Plant         |
 |                |  |  Control       |  |  Control       |
 +----------------+  +----------------+  +----------------+
```

*% Analysis   *% Defects   *Compactibility
*Pour Temperature *Run Time Analysis   *Physical
                                             Propeties
*Melt Record   * Hardness   *Chemical Make-Up
                   * Metallography
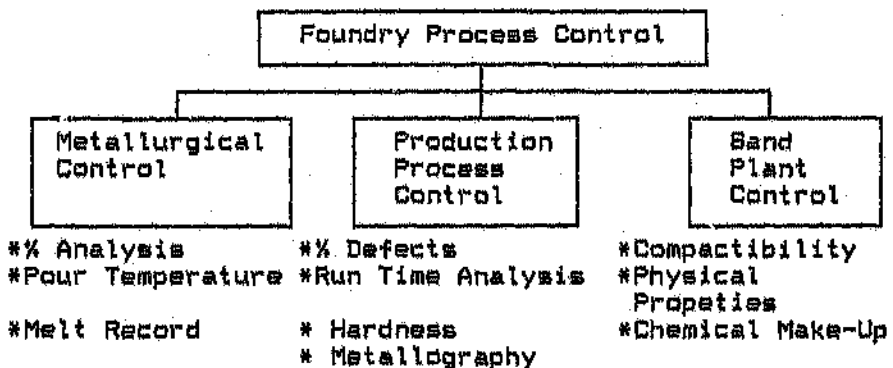
Therefore, to outline the details each control aspect will be examined separately.

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.
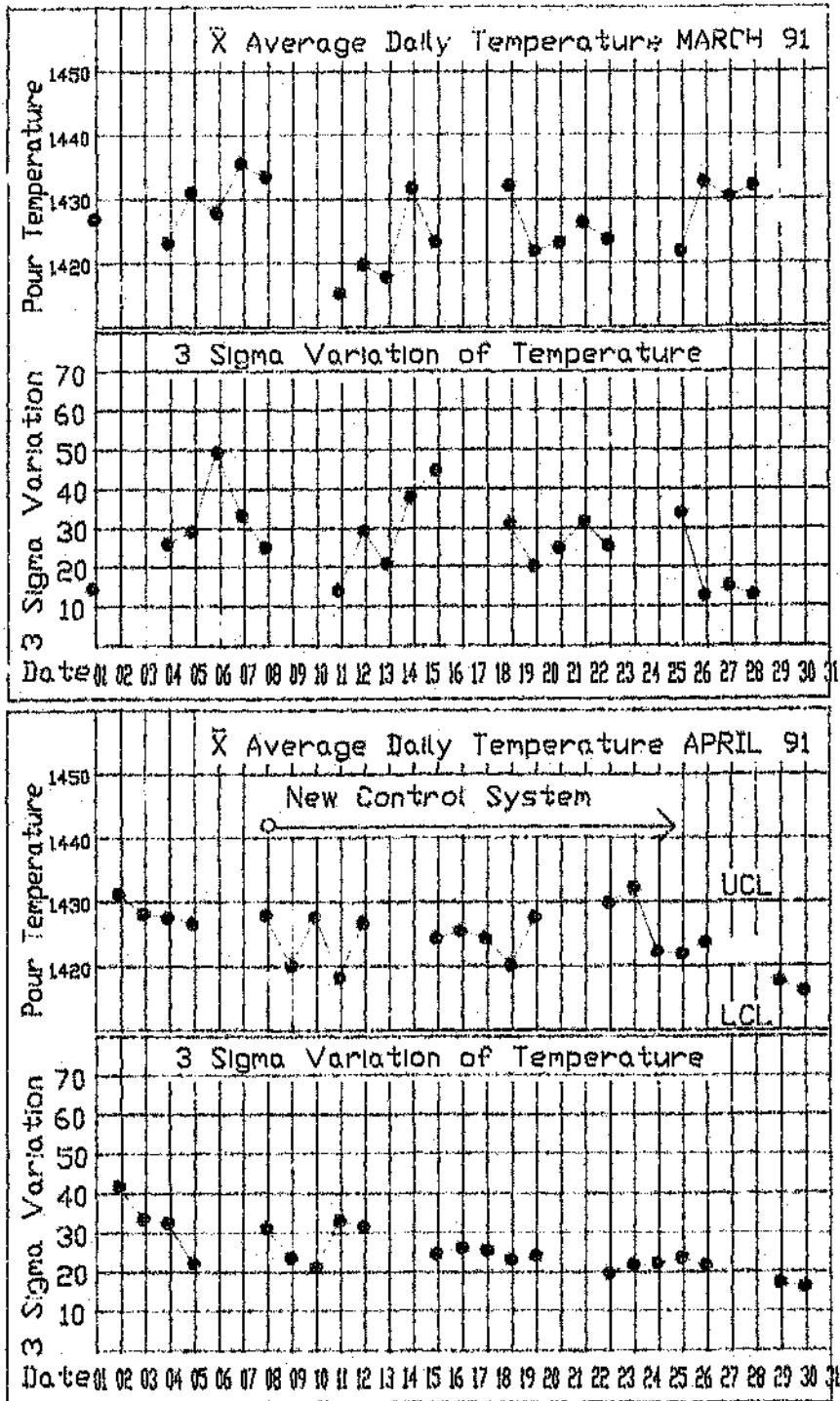
Fig. 8.2

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 res.lts. Fig 8.5 demonstrates this.
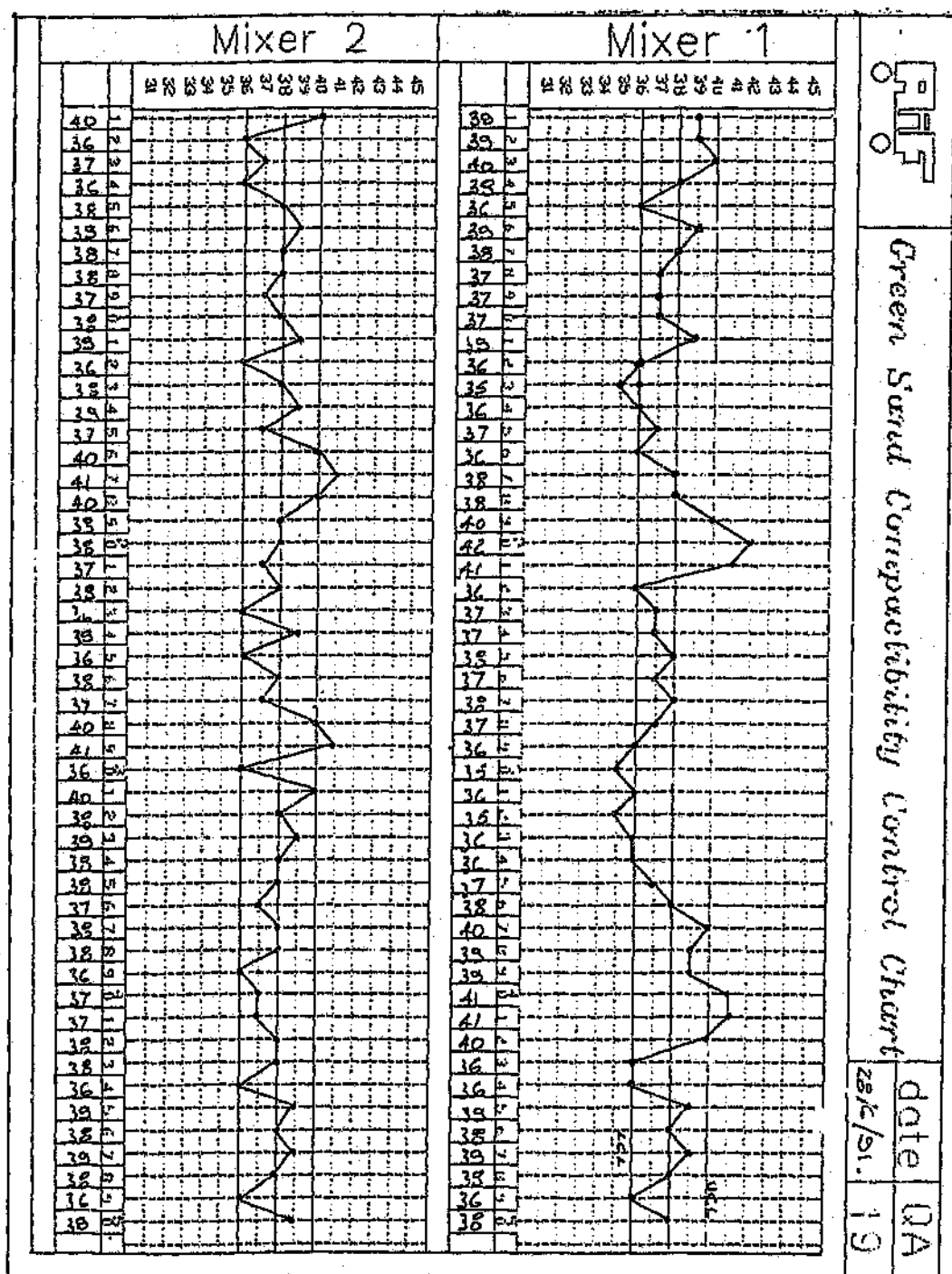
Fig. 8.3

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 reject' only production batches in excess of 100 components are considered, effectively filtering out most trials.

In considering the most suitable m ns 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 (8)

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:-

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

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	58	0.086	0.168		123E91	216	865	43	0.050	0.068
10D91	322	468	58	0.126	0.168		123E91	322	291	15	0.052	0.068
11D91	322	383	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	0.112	0.168		15F91	322	603	18	0.030	0.074
22D91	919R	152	27	0.178	0.168		10F91	322	417	16	0.039	0.074
24D91	322	498	83	0.167	0.168		11F91	322	513	0	0	0.074
24D91	216	693	199	0.287	0.168		12F91	322	245	12	0.049	0.074
25D91	329	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	800	39	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
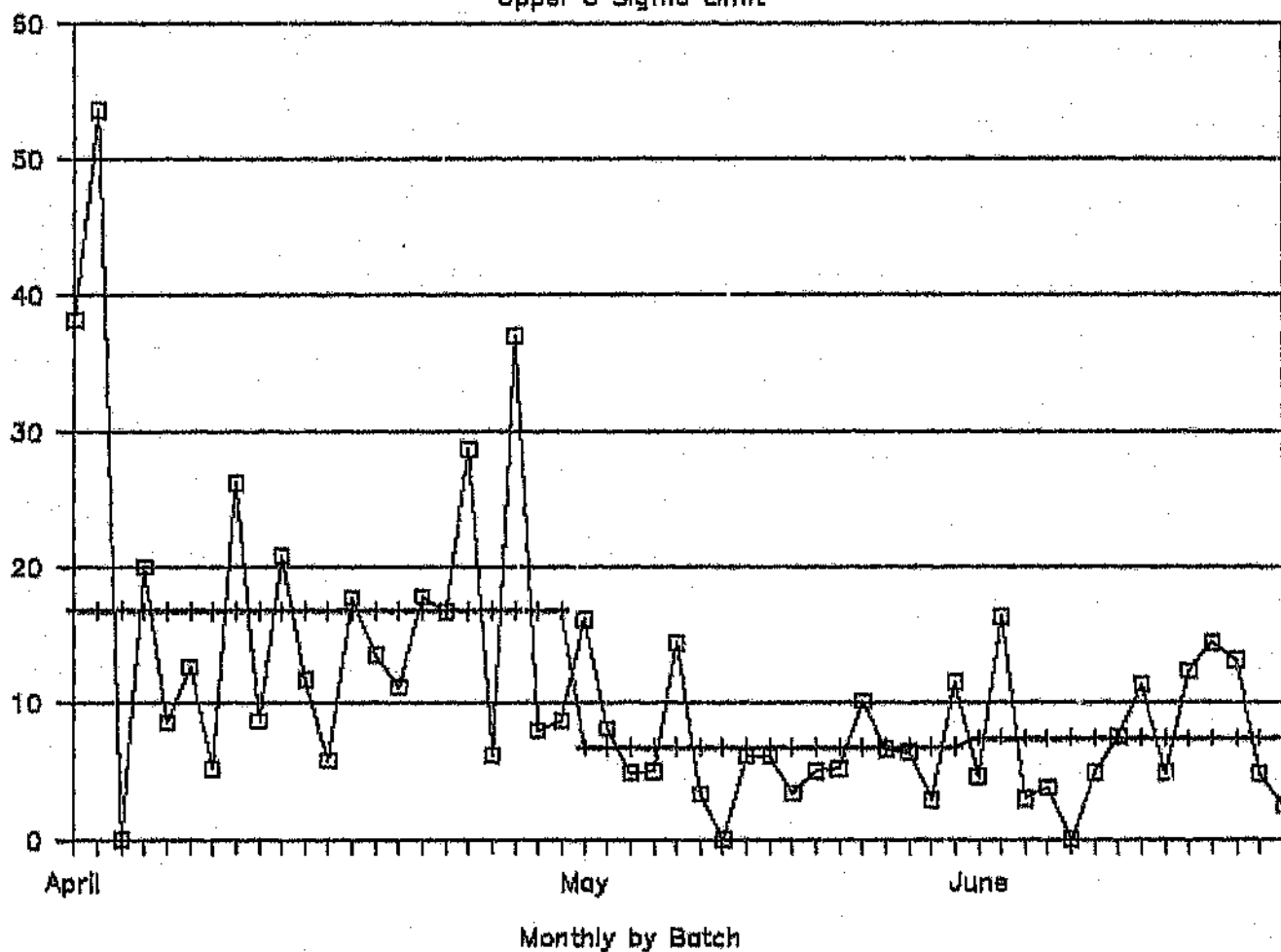

Fig. 8.4

-75-

Percentage Defective

Monthly by Batch

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
prio ity 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
Q8K-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 Q8K-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.
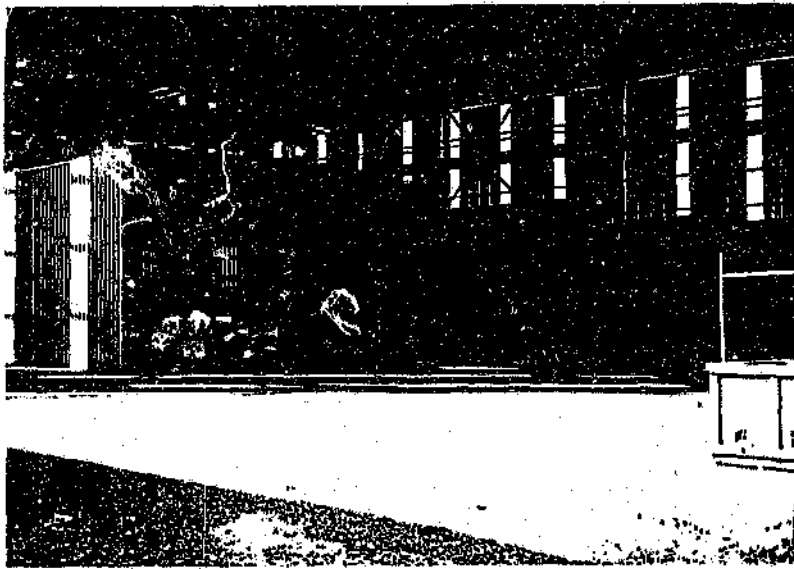
Photograph 2 – Raw materials being carefully weighed
before charging into the furnace.
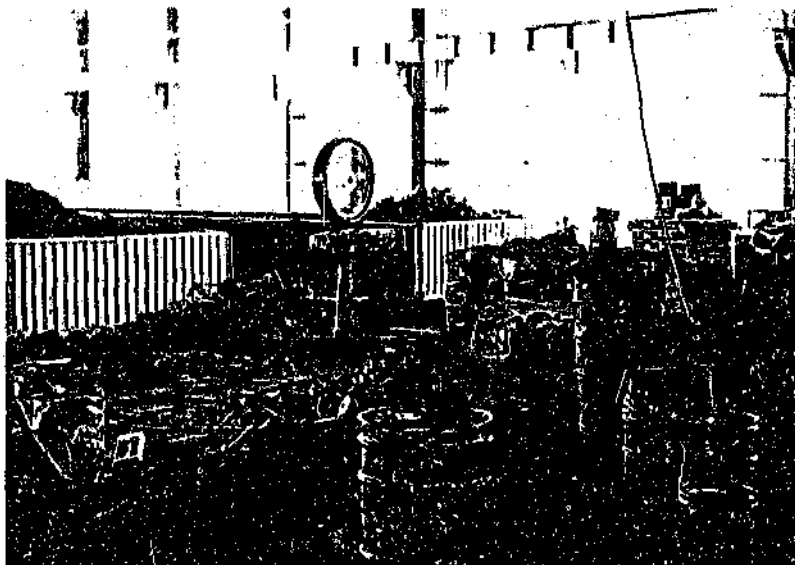
Photograph 3 - Metal being tranfered from melting
to holding furnace.
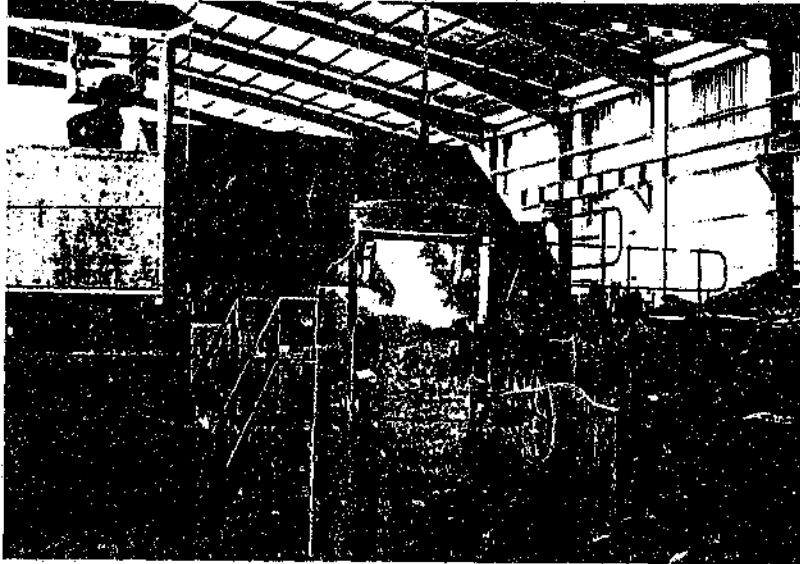
Photograph 4 - Kunkel Wagner automatic moulding
line
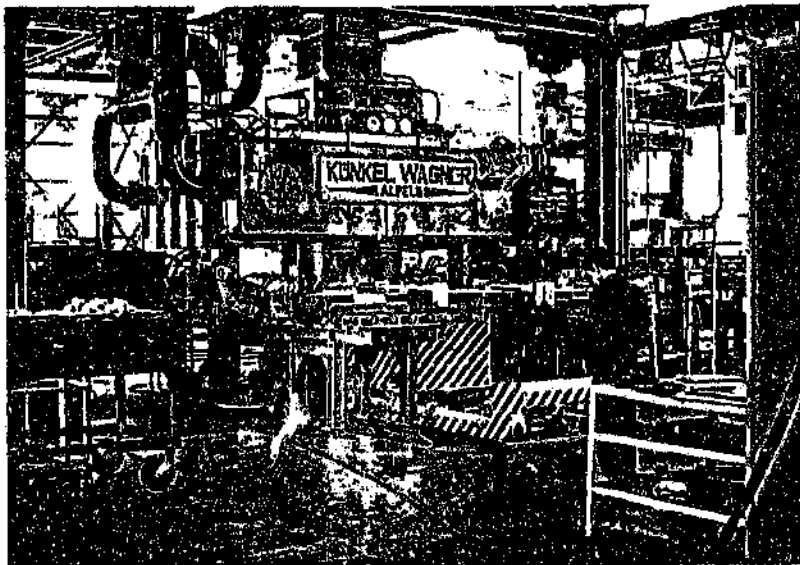
Photograph 5 - Pouring and cooling lanes for the
Kunkel Wagner.
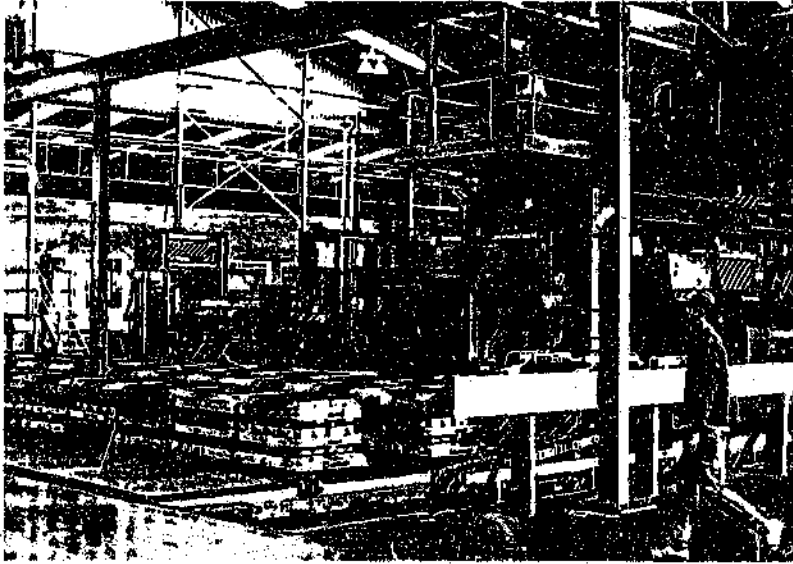
Photograph 6 - Clean castings being taken out of the
'shake-out'

Photograph 7 - Control panel for the automatic
green sand plant
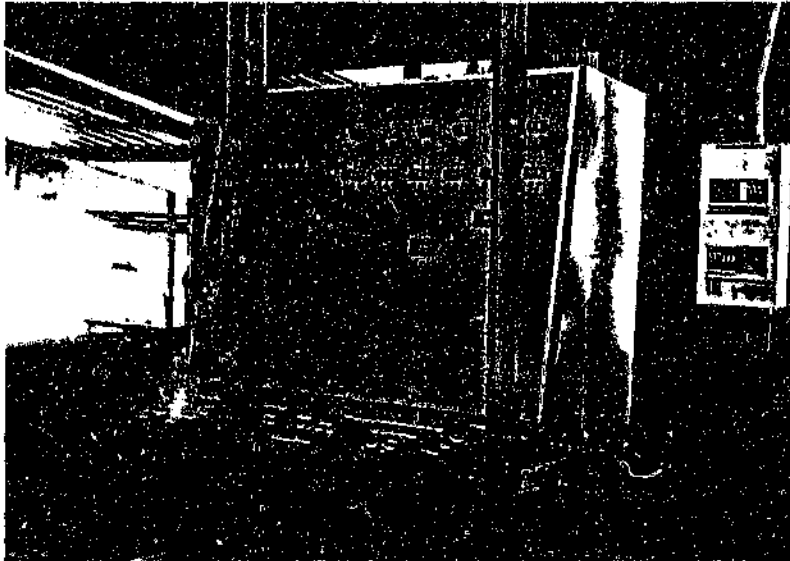
Photograph 8 - Mixer mill. Materials are gravity
fed from the silos

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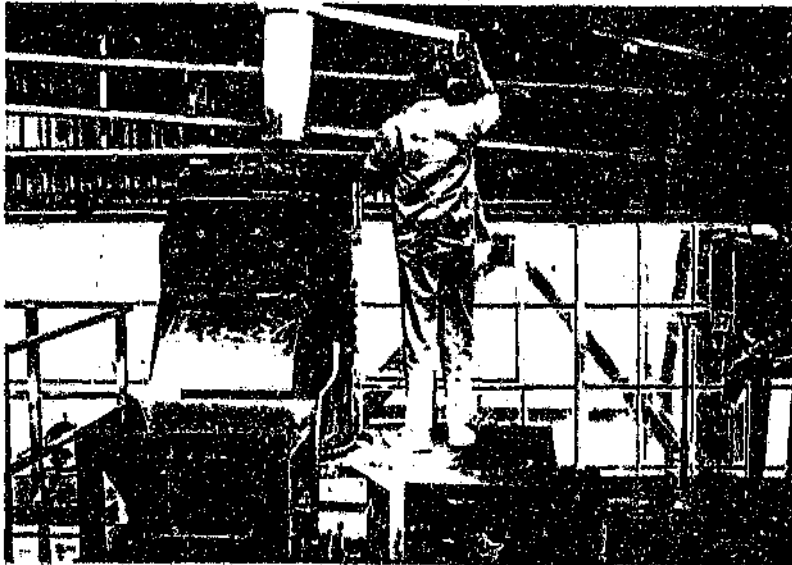
Photograph 11 - Core moulding machine - after
automatic cycle is completed.

Photograph 12 - Removing core and resetting the
automatic cycle.
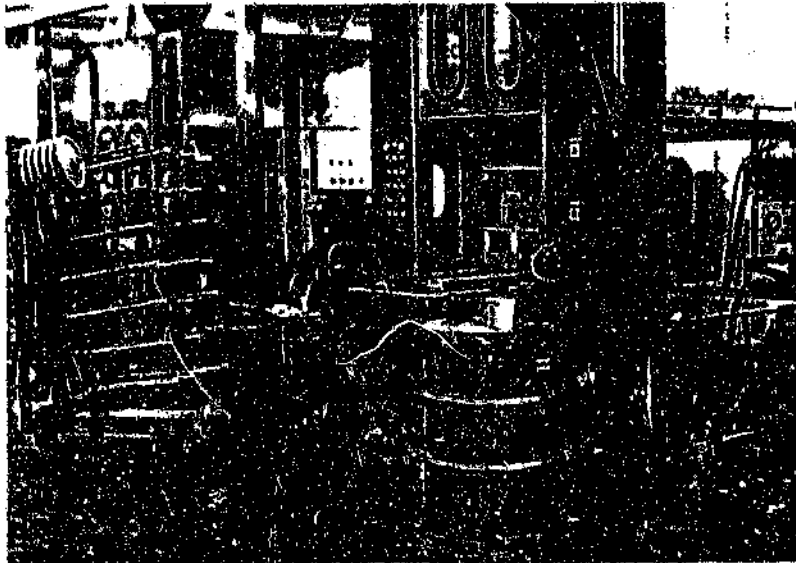
Photograph 13 - Inocculating a pouring ladle -
before delivery to the line.

Photograph 14 - Complete mould ready for closing.
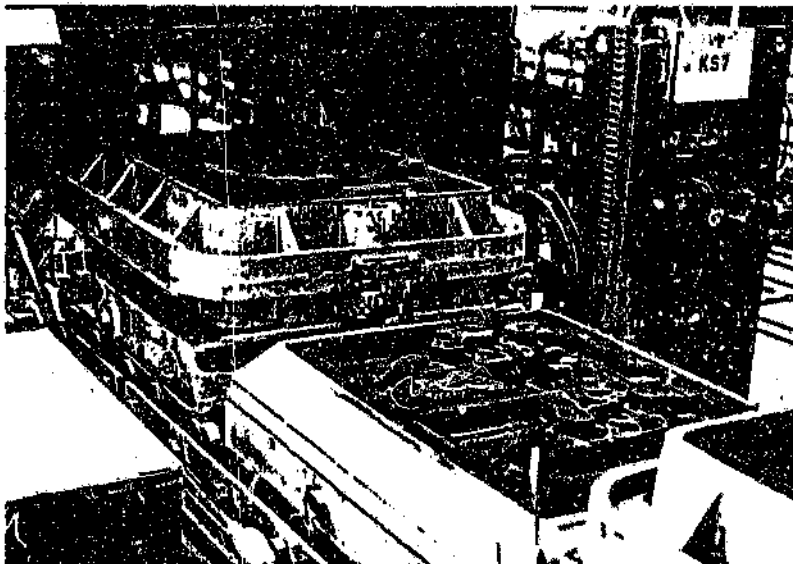
Photograph 15 — Pouring metal into mould on the
pouring lane.
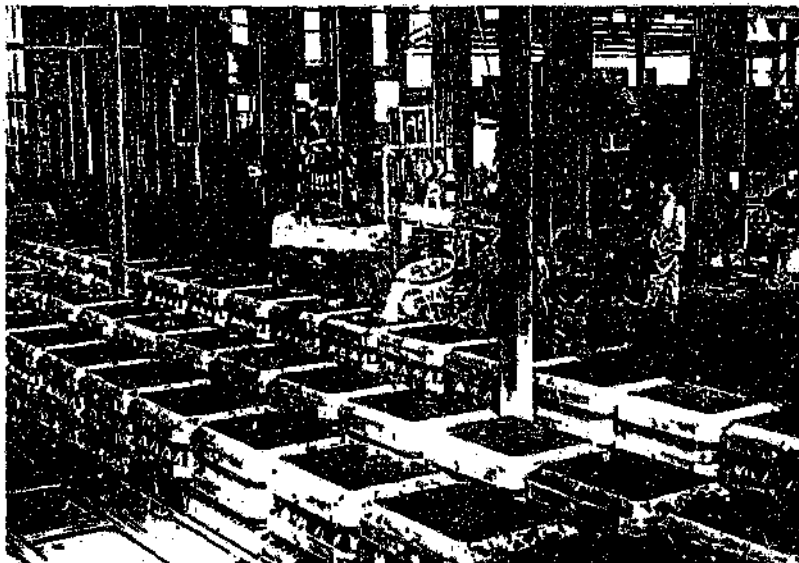
Photograph 16 — Shot blast machine for cleaning
sand off castings.
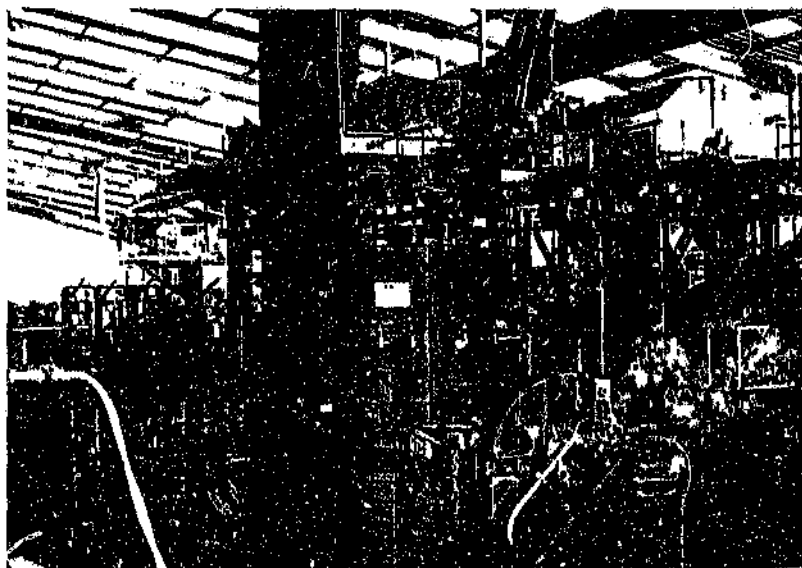
Photograph 17 - Removing flash and feeders by
grinding.

Photograph 18 - Castings ready for inspection
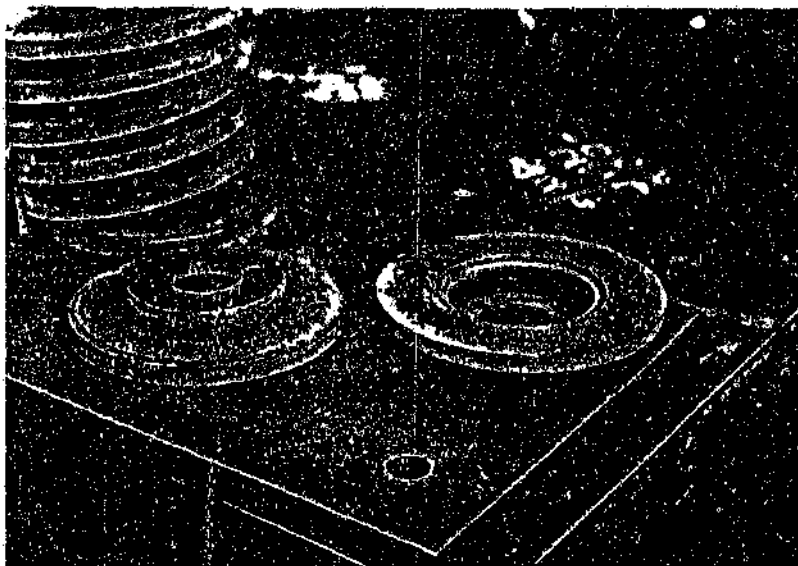
Photograph 19 - Carefully visual inspection - marking
all defects.
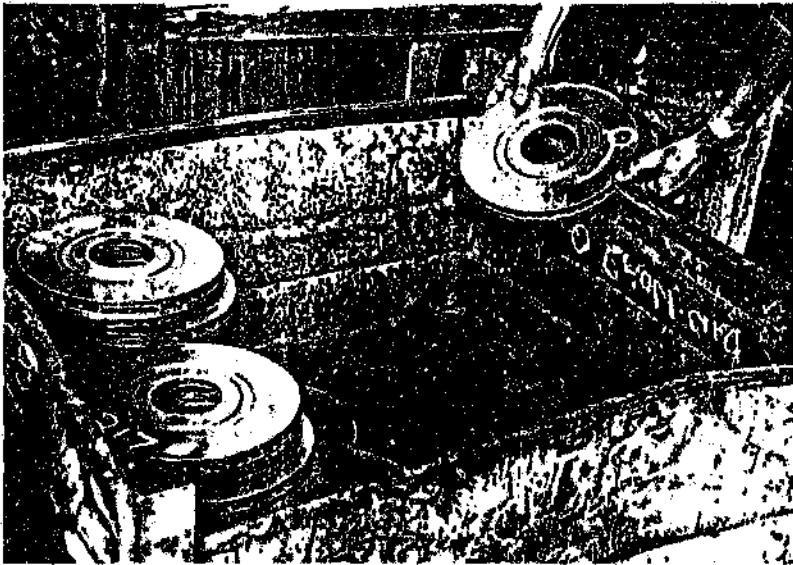
Photograph 20 - Classifing reject castings for
statistical analysis.
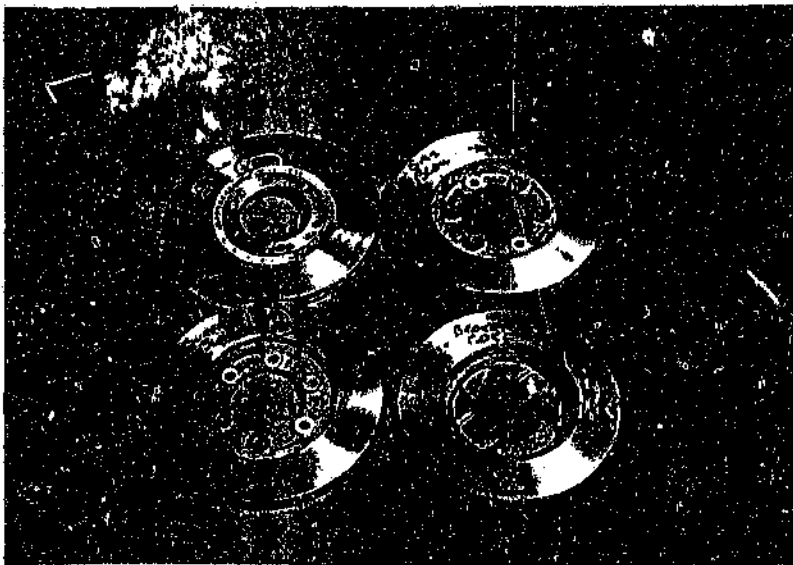
Photograph 21 - Sectioning castings to examine
core metallurgy.
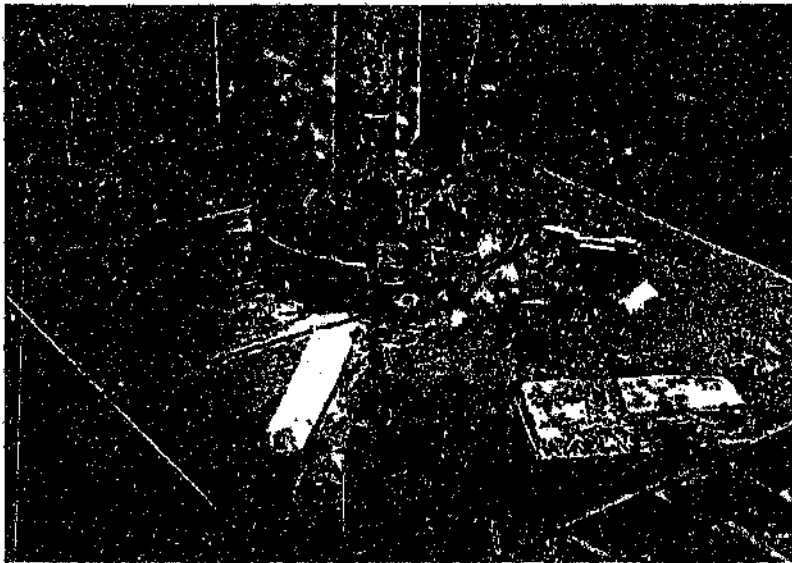
Photograph 22 - Detail of green sand half mould

Photograph 23 - Laboratory equipment for determining
sand characteristics.
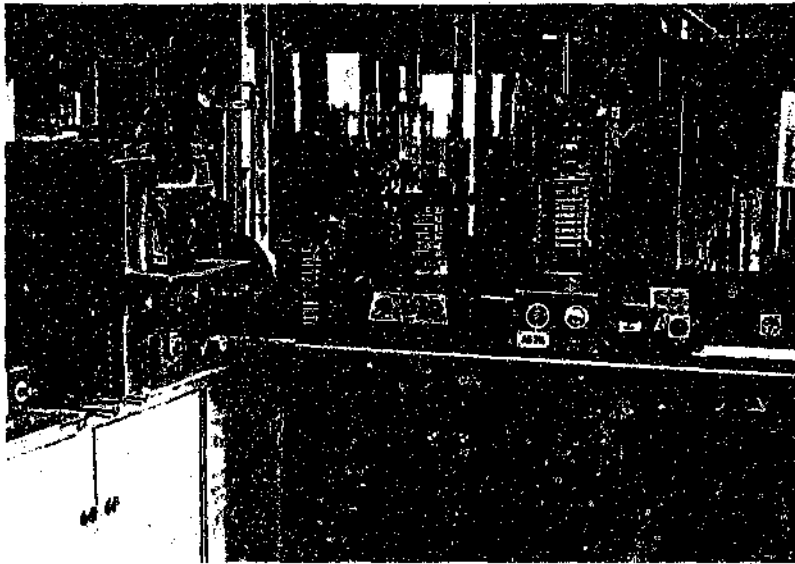
Photograph 24 - Equipment used for measuring
quality of sand.
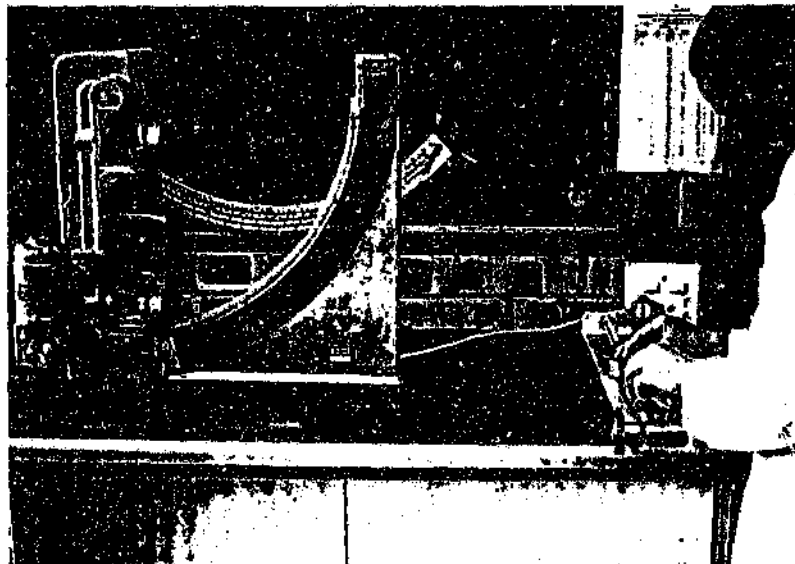
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