CERTIFICATE

Department of Mechanical Engineering

Certified that this is a bonafide report P- 469

of

the thesis work done by

Mr. G. KUMARA RAJA SINGH

(Reg. No. 9937H0004)

at

KUMARAGURU COLLEGE OF TECHNOLOGY

COIMBATORE – 641 006

During the year – 1999 – 2000

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FUEL GAUGE CALIBRATION USING TAGUCHI TECHNIQUES

p-469

Thesis submitted in partial fulfillment of the requirements for the award of the degree of
MASTER OF ENGINEERING IN MECHANICAL ENGINEERING
(INDUSTRIAL ENGINEERING)
of BHARATHIAR UNIVERSITY

By

G. KUMARA RAJA SINGH
(Reg. No. 9937H0004)

Under the Guidance of
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DEPARTMENT OF MECHANICAL ENGINEERING
KUMARAGURU COLLEGE OF TECHNOLOGY
(Affiliated to Bharathiar University)
COIMBATORE – 641 006

1999 - 2000

DEDICATED TO MY LORD
JESUS CHRIST

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TO WHOM SO EVER IT MAY CONCERN

This is to certify that **Mr G Kumara Raja Singh,** doing final year ME (Industrial Engineering) at Kumaraguru College of Technology – Coimbatore, has done a project in our organisation.

The details are :

- Title of the Project : ***FUEL GAUGE CALIBRATION USING TAGUCHI TECHNIQUES***
- Period of Project : *June 2000 to December 2000*
- Department : *Total Industrial Engineering*
- Attendance & Conduct : *Good*

We wish him the very best for a bright future.

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CERTIFICATE

This is to certify that this thesis work entitled " **FUEL GAUGE CALIBRATION USING TAGUCHI TECHNIQUE** " being submitted by **G. KUMARA RAJA SINGH,** (Reg. No. 9837H0004) for award of the degree of **MASTER OF ENGINEERING IN MECHANICAL (INDUSTRIAL ENGINEERING),** is a bonafied work carried under my guidance. The results embodied in this thesis have not been submitted to any other University or institute for the award of any Degree or Diploma.

N. Gunasekeran
....

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ACKNOWLEDGEMENT

The success of any project depends on teamwork and co-operation of number of people. The author would like to take this opportunity to express ~~our~~ his gratitude to the people whose support and guidance made to this project a grand success.

At this delightful moment of having accomplished project on **FUEL GAUGE CALIBRATION USING TAGUCHI TECHNIQUE,** The author owe thanks to **Dr. K.K. Padmanaban, B.sc. (Engg) M.Tech. Ph.D.,** Principal of our college, for his constant encouragement and constructive suggestions.

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G. KUMARA RAJA SINGH

(Reg.no.9837H0004)

SYNOPSIS

SYNOPSIS

Now days, the globalization forces the Indian industries to concentrate more on quality of product and process in a continual basis in order to survive in the market. The automobile industries also cannot escape from it because of more competition in global market and arrival of multinational companies.

This project deals with automobile dashboard instrument manufacturing industry's real time problem in manufacturing particularly fuel gauge of a car.

The fuel gauges are calibrated to the positions of Empty, Half, Full in order to assure their quality after, manufacturing. The error in the range setting is a problem in most of the fuel gauges due to the process in the selected study.

The entire manufacturing processes are studied and the reason for this error is found out by implementing Reverse Engineering technique. The influencing parameters of the fuel gauge on the range setting are studied and the most influencing parameters are got from the reverse engineering methodology parameters are the input of the Taguchi technique to eliminate the error and to optimize the process parameter and their response.

The experiments are conducted with the critical parameters found in the reverse engineering methodology and its interaction effects are also studied. The intended angle of the pointer of the fuel gauge is optimized based on the experiments conducted.

CONTENTS

INTRODUCTION

INTRODUCTION

The customers need and requirements are changing day-to-day. The customers expect improvement in the quality of any product (or) service. The global competition has made the industries to think about improvements of their products / service in continual basis. Every sector in a company is in top gear to meet such situation.

The thesis concentrate on a real time manufacturing problem in an automobile dash board instrument manufacturing industry, where the gauges undergo calibration in order to ensure its quality after manufacturing. Most of the cases, there is an error in the fuel gauge, which results in higher percentage of rejection. To eliminate the error in the calibration, an exhaustive study on the existing manufacturing system is carried out and the reason for the error in the calibration is traced and analyzed. And ultimately a necessary corrective action is implemented and an alternative method is suggested to prevent the reoccurrence of the above problem in future.

Many companies are doing extremely well in their business inspite of the global competition and recession. This could have been possible because of their consistent effect in maintaining and improving quality of the products and processes.

The unimaginable changes are taking place in the automobile industries. The continuous evaluations are taking place in the design of the components of an automobile. We have cars on road with the colors, which we have not imagined yet. What was not important is improvement today in the area of automobiles.

The fuel gauges are the meters found in the dashboard of cars. The company pricol, manufactures fuel gauges and their meters have involved us in the improvement of their fuel gauges.

INTRODUCTION ABOUT THE ORGANISATION

Name of the organization : Premier Instruments and Controls Ltd.

Address : Periyanaicken Palayam

Coimbatore – 641020.

1.1 Pricol's Inception:

Pricol stands for "**Premier Instruments and Controls Limited**"

Pricol was established in the year 1974 by Mr.Vijay mohan. It was established to produce automotive instruments, with in a short span of time, the company grew to the positions of a leader in the field. Today it maintains quality levels that match the best in the world.

Pricol's Products:

Today Pricol is well enriched itself as a supplier to industries, which include textiles, process industry, defense electronics and small machine tools.

In the earlier days Pricol's main products were,

1. Speedometers
2. RPM meters
3. Temperature & Pressure gauges
4. Tank units
5. Small switches.

A part from the above, Pricol manufacturers small machine tools like manual and pneumatic presses, coil winding machines, precision centreless grinders, screen printing machines.

Electrical and electronic products from Pricol:

Besides the above products, Pricol is manufacturing products such as,

1. Electrical pressure gauges.
2. Electrical temperature gauges.
3. Electronic tachometers.
4. Electronic tax-fare meters.
5. Electronic sensors.

Pricol's manpower & plants:

"Best people only can make the best things "pricol has the talented, dedicated and smart working people". Pricol has the strength of around 3650 employees in which around 720 are technical / clerical staff. Pricol has four plants, as listed,

Plant I: Situated at P.N. palayam. Coimbatore. It was established first it is also the big one.

Plant II: Situated at Gurageon, New Delhi.

Plant III: Situated at Chinamatham palayam, Coimbatore.

Plant IV: Situated at Karamadi.

Pricol's corporate office is situated in Coimbatore city itself and has offices in four metropolitan (New Delhi, Mumbai, Calcutta, Chennai) and it has representatives all over the country.

Pricol's achievement:

Sustaining the Vital edge at Pricol is its Research & Development department (R&D) which cuts across the boundary of more technological commitment to satisfy the customer.

Pricol is commitment to TQM has won international acceptance. It was the first company in the automotive instrumentation industry to get the ISO 9001 certification in the year 1993.

Pricol has introduced the concept of re engineering a trend that gaining momentum worldwide. Pricol has introduced the Total Productive Manufacturing [TPM] concepts in the company.

Pricol is supplying its products to major Indian concerns like,

1. Telco
2. Mahindra & Mahindra
3. Maruthi
4. Hindustan motors.

Apart from this Pricol is exporting the products to,

1. USA
2. UK
3. Canada
4. Australia

LITERATURE SURVEY

BASIC CONCEPTS OF TAGUCHI TECHNIQUES

2.1 Taguchi approach to quality:

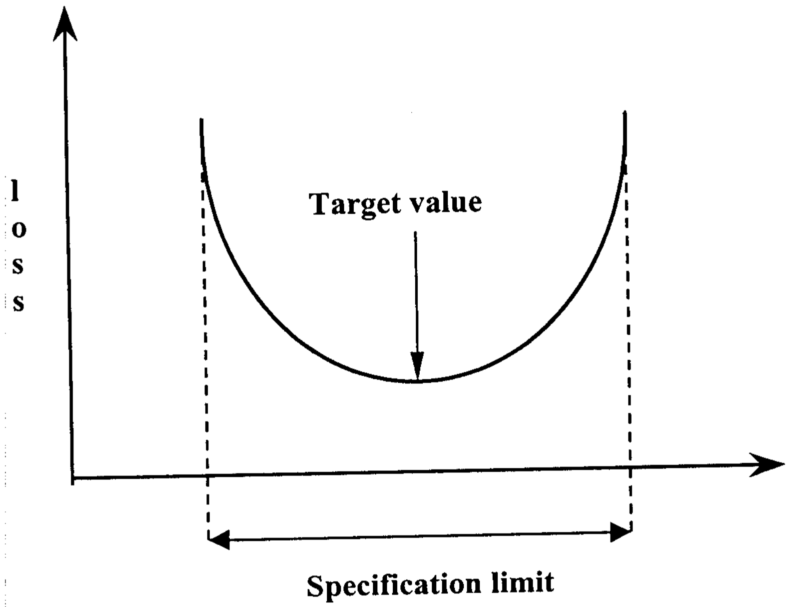
[7] According to Dr. J.M. Juran (1964) quality as "fitness for use" Philip Crosby the leading promoter of the "zero defects' concept and the author of quality is Free (1979), defines Quality as "Conformance to Requirement". Dr. Deming says that quality should be aimed at the need of the customer, present and future. American society for quality control (1983) defines quality as "the totality of features and characteristics of a product or service that bear or its ability to satisfy given needs"(1983). According to Genichi Taguchi Quality [2] is the loss a product causes to society after being shipped, other than any losses caused by its intrinsic functions".

Quality Loss

[2] Product quality has been measured by comparing critical product characteristics to engineering specifications for the product. Product specification are still important, but the focus today is more on controlling process characteristics, Since it is the production processes which determine the quality of the finished products. To reduce process and product variability and more quality characteristics close are made close to target values. This results in reduced Quality loss.

Quadratic Quality / Loss Function

This loss function [8] clearly shows that as characteristic moves further away from a target value, an increased loss is incurred. We would need to know the actual losses for some selected values of the characteristics when designing engineering experiments in order to determine the exact form of the loss function. The important point is that it is to improve quality, or to decrease loss. We must strive to have process and product characteristics as close to their target values as possible.



Taguchi quality system:

Quality frequency [7] divide quality system into two parts: quality of design and quality of conformance. Taguchi refers to these two parts as off line quality control and on line quality control.

Off line quality control concerned with:

1. Correctly identifying customer needs and expectations.
2. Designing a product, which will meet customer expectations.
3. Designing a product, which can be consistently and economically manufactured.
4. Developing clear and adequate specifications, standard procedures and equipment for manufacturing.

Production / quality system cycle:

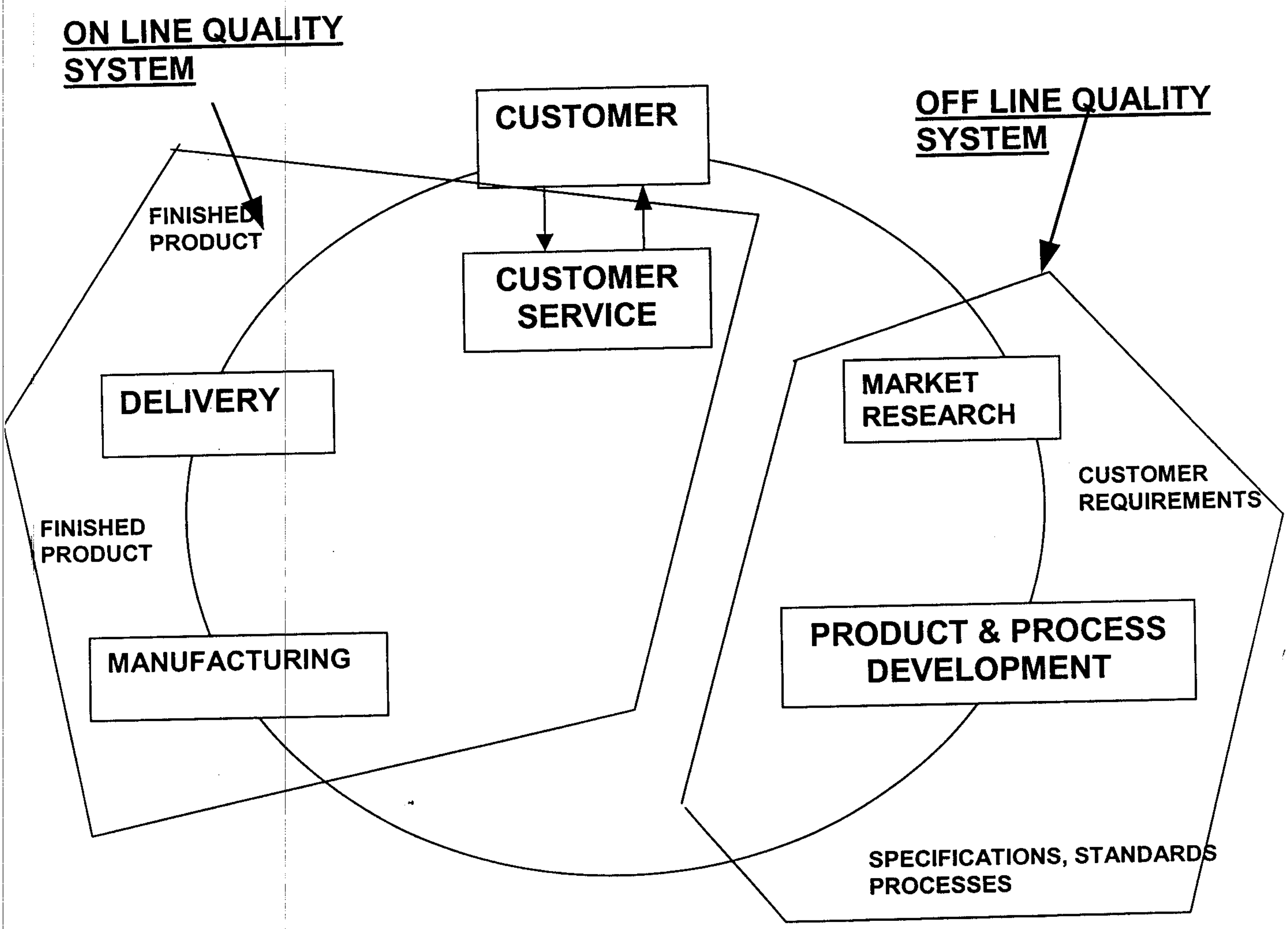


FIGURE: 1

TABLE: 1 TAGUCHI'S QUALITY SYSTEM :

OFF -LINE QUALITY CONTROL	**Stage 1** **PRODUCT DESIGN**	**Concerns:** 1. Identify customer needs and expectations 2. Design a product to meet customer needs and expectation 3. Design a product which can be consistently and economically manufactured	**QA Steps:** 1. System design 2. Parameterdesign 3. Tolerance design
	Stage 2 **PROCESS DESIGN**	**Concerns:** 1. Develop clear and adequate specification procedures and equipment for manufacture	**QA Steps:** 1. System design 2. Parameter design 3. Tolerance design
ON -LINE QUALITY CONTROL	**Stage 1** **PRODUCTION**	**Concerns:** 1. Manufacture products with in specifications established during product design using procedures developed during process design	**Form 1** Processdiagnosis and Adjustment **Form 2** Prediction and correction **Form 3** Measurement & action
	Stage 2 **CUSTOMER RELATIONS**	**Concerns:** 1. Provide service to customers and use information on field problems to improve products and manufacturing process designs.	**Actions:** 1. Repair, replacement or refund 2. Feed back information on fields problems. 3. Change product and process specificatrions / design

Stages in off line quality control:

(a) Product design stage.
(b) Process design stage.

During product design stage a new product is developed or an existing product is modified. The goal here is to design a product, which is manufacturable and will meet customer requirements. During the process design stage, production and process engineers develop manufacturing processes to meet the specifications developed during the product design stage.

Activities 1,2, and 3 are part of product design; activity 4 takes place during the process design stage. Taguchi developed a three-step approach for assuring quality with in each of the two stages of off line quality control. These steps are normally called system design, Parameter design and tolerance design.

On Line Quality Control

[7] It is concerned with manufacturing products with in the specifications established during product design using the procedures developed during process design. Also, product and process designs may be revised if feed back from customers reveals opportunities for improvement.

Stages of on line quality control:

Production quality methods are
Three forms

1. Process diagnosis and adjustment.
2. Prediction & correction
3. Measurement & action.

Application of Optimization in Engineering Fields: [9]

1. Design of aircraft and aerospace structures for min weight
2. Finding the optimal trajectories of space vehicles.
3. Design of civil engineering structures for minimum weight.
4. Selection of machining conditions in metal cutting process for minimum production cost.
5. Optimum design of electrical network.
6. Optimal PPC.
7. Minimum weight design of structures for earthquake, wind and either types of loading.
8. Design of water resources system for maximum benefit
9. Inventory control.
10. Design of pumps, turbines and heat transfer equipment for max efficiency.
11. Shortest route taken by a sales man visiting different cities.
12. Analysis of statistical data and building empirical models from experimental results to obtain the most accurate representation of the physical phenomenon.
13. Optimal design of chemical processing equipment and plant.
14. Design of optimum pipeline networks for process industries.
15. Selection of site for an industry.
16. Planning of maintenance and replacement of equipment to reduce operating costs.
17. Allocation of resources or services among several activities to maximize the benefit.
18. Planning the best strategy to obtain maximum benefit in the presence of competitor.

2.2 Experimental Design techniques:

[4] Experimental design were used to identify which combination of settings or "levels" for certain key factors produced the best average value for the product or process characteristics of interest.

In the Taguchi approach to quality engineering the primary role of experimental design is to make the process and product insensitive (Robust) to variation in uncontrolled factors.

Experiment:

Experiment is a series of trials or tests, which produce quantifiable outcomes. An experiment where the outcome can be completely predicted in advance is then called a "deterministic experiment". Industrial experiments are generally performed to explore, estimate, and confirm.

- Exploration
- Estimation
- Confirmation

Exploration:

Gather data to learn more about process or product characteristic.

Estimation:

Use data to estimate the effects of certain variables on other variables.

Confirmation:

Gather data to verify a hypothesis abut a relationship among variables.

Experimental design techniques:

[4] Statisticians by themselves do not design experiments, but they have developed a number of structured schedules called experimental designs. Which they recommend for taking measurements.

These designs have certain rational relation ships to the purpose, needs, and physical limitations of experiments design also offer certain advantages in economy of experimentation and provide straight forward estimates of experimental effects and valid estimates of variance.

There are a number of ways in which experiment designs might be classified, for example,

1. By the number of experimental factors to be investigated.
2. By the structure of the experimental design (e.g..blocked, factorial,nested or response surface design)
3. By the kind of information the experiment is primarily intended to provide (e.g.. estimates of effects, estimates of variance)

Basic terminologies in experimental design:

Factor:

A factor [4] is one of the controlled or uncontrolled variables whose influence upon a response is being studied in the experiment. A factor may be quantitative e.g.. temperature in degrees, time in secs

A factor may also be qualitative e.g.. different machines, different operators, switch on or off.

Levels:

The "level of a factor are the values of the factor being examined in the experiment. For quantitative factors, each chosen value becomes a level.

e.g.. if the experiment is to be conducted at four differant temperatures then the factor temperature has four levels. In case of qualitative factors, switch on or off become two levels for the switch factor.

Treatment:

A treatment is a single level assigned to a single factor during an experimental run. A treatment combination is the set of levels for all factors in a given experimental run.

e.g., an experimental run using an 800 degree temperature, machine 3, operator "A", and switch off would constitute one treatment combination

Experimental units:

The experimental units consist of the objects, materials or units to which treatment are being applied. They may be biological entities, natural materials, fabricated products etc.

Experimental design:

The formal plan for conducting the experiment is called experimental design.

Block:

A factor in an experimental program that has influence as a source of variability called "block". A block is a portion of the experimental material or of the experimental environment that is likely to be more homogeneous with in it than between different portions.

Important tools of experimental design:

Blocking: (planned grouping)

[1] Beyond selected factors for study; there are often other "background" variables that may also influence the outcomes of the experimental program.

Variables such as raw material batches, operators, machines, or days the influences of these variables upon the response are not under the control of the experimenter. These variables are commonly called "blocks".

When an experimenter is aware of blocking variables it is often possible to plan experimental programs to reduce their influence. In designing experiment, wide use of the reduced variability occurring with in blocks to use is made of the reduced variability occurring with in blocks to accentuate the influences of the studied factors. Designs that make use of this uniformity with in block are called blocked designs and the process is called planned grouping.

Randomization:

The sequence of experiments and or the assignment of specimens to various treatment combinations in a purely chance manner is called "randomization". Such assignment increases the likelihood that the effects of uncontrolled variables will balance out.

Replication:

"Replication" is the repetition, the rerunning of an experiment or measurement in order to increase precision or to provide the means for measuring precision, replication provides an opportunity for the effects of uncontrolled factors or factors unknown to the experimenter to balance out and thus, through randomization acts as a bias-decreasing tool. Replication also helps to detect gross error in the measurement. Rerun experiments are commonly called replicates.

Reproducibility and repeatability:

Reproducibility measures the variability between items manufactured on different days on different machines. Repeatability measures sources of variability that are more local or immediate assignable to items measurements or the variability occurring between adjacent items manufactured in sequence.

PROBLEM DEFINITION

PROBLEM DEFINITION

3. Introduction

Now days, the Globalization forces the Indian industries to concentrate more on quality of product and process in a continual basis in order to survive in the market. The Indian automobile industries also cannot escape from the stiff competition in the global market. This paper deals with a real time manufacturing problem in an automobile dash board instrument manufacturing industry, where the gauges under go calibration to ensure its quality after manufacturing. But most of the cases there is an error in the fuel gauge, i.e., the pointer does not show the correct reading are normally called as "error in the range setting". The operator eliminates the above problem through trial and error method. But most of cases the above method does not provide solution to the error in the fuel gauge. Hence, such type of error gauges under goes rejection, leads to higher percentage of rejection.

Fuel gauge

The fuel gauge taken for study is basically operates on the electrical principle. Such types of gauges have more sensitive to variation. Hence continuous monitoring and control of process characteristic is necessary to ensure its quality.

Elements and structure of the fuel gauge

The fuel gauge contains following elements, namely

1. Bottom bobbin
2. Main magnet
3. Axle pointer
4. Silicon oil
5. Top bobbin
6. Return magnet
7. Wire winding
8. Lug plate and terminal
9. Resistor

10. Magnet cover
11. Dial
12. Pointer

The following figures provide a detail structure of the fuel gauge.

Assembly & calibration

The assembly sequence of fuel gauge as follows

1. The lug plate is fixed in the terminal nut by riveting process as shown in the figure : 2
2. The lug plate and terminal nut assembly is fixed in the top bobbin.
3. The main magnet is fixed in the axle pointer by a magnet driving process is shown in the figure : 3
4. The silicon oil is filled in the bottom bobbin.
5. The main magnet and axle assembly is placed in the bottom bobbin.
6. The return magnet is fixed in the top bobbin as shown in the figure : 4
7. Assembly of top and bottom bobbin as shown in the figure : 5
8. Wire winding on the top and bottom bobbin assembly.
9. Resistor is soldered in the lug plate as shown in the figure : 6
10. The whole assembly is placed in the magnet cover as shown in the figure : 7
11. The dial is fixed on the top bobbin using the terminal nut.
12. The pointer is fixed on the pointer axle as shown in the figure : 8
13. The entire assembly is fixed in the calibration stand and the calibration is carried out as shown in figure : 9

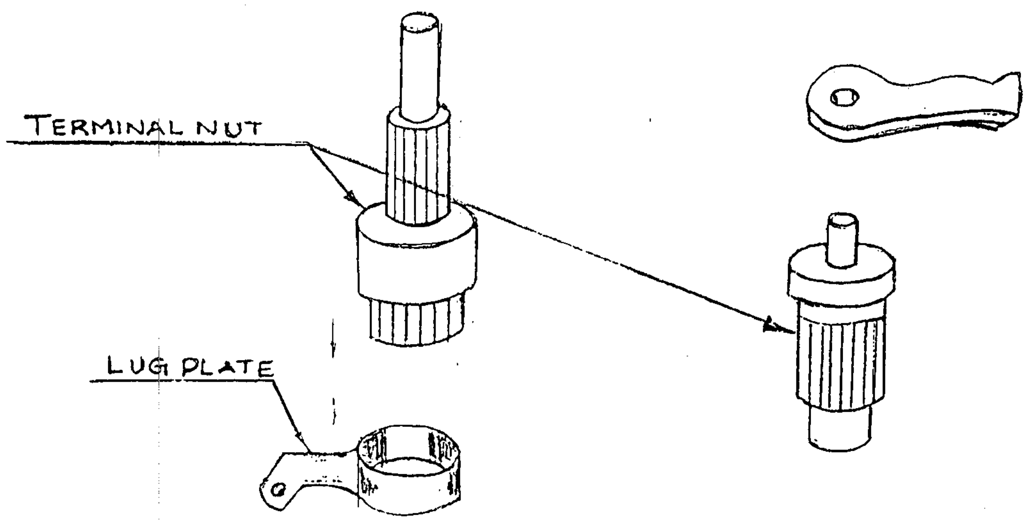


FIGURE:2

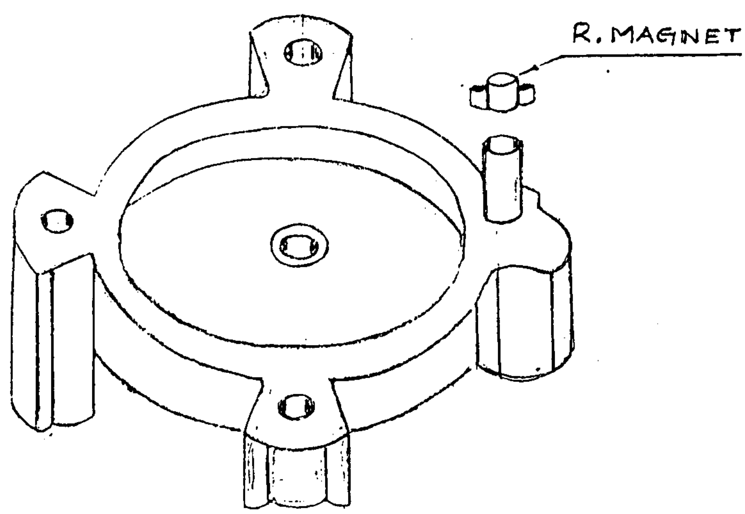


FIGURE:4

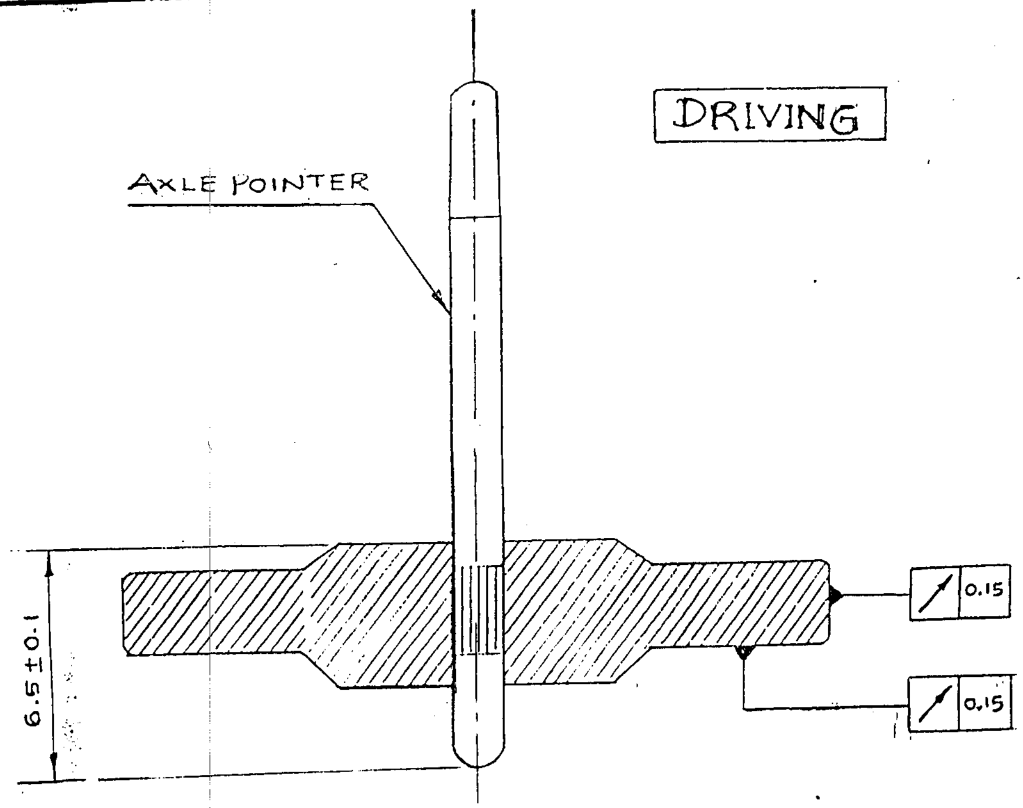
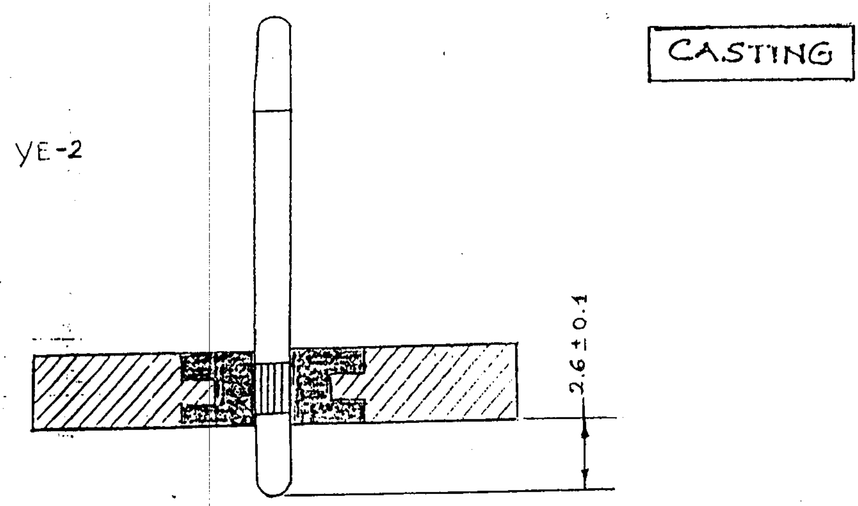


FIGURE:3



"ALL DIMENSIONS ARE IN MM"

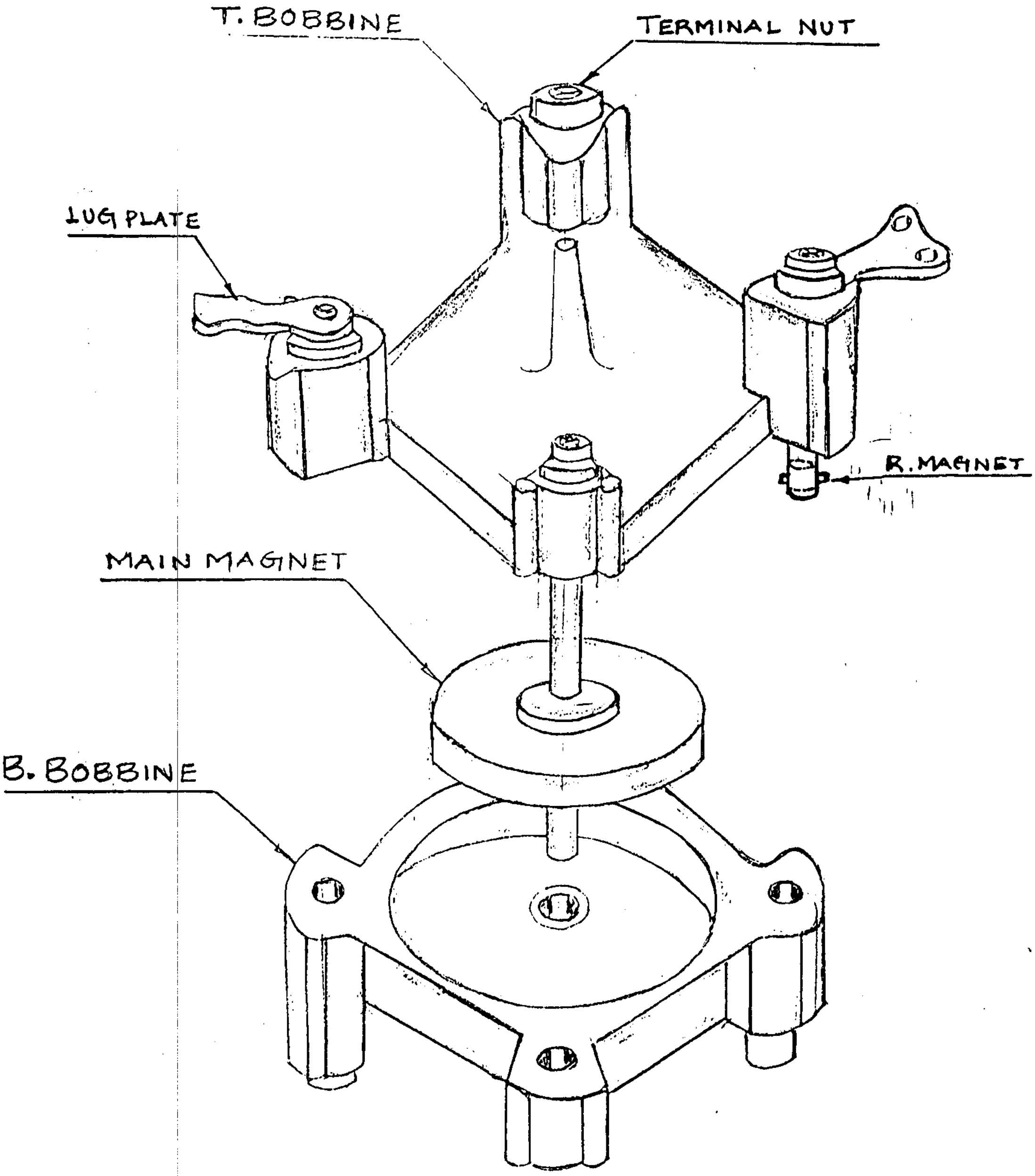

T. BOBBINE
TERMINAL NUT
LUG PLATE
R. MAGNET
MAIN MAGNET
B. BOBBINE

FIGURE: 5

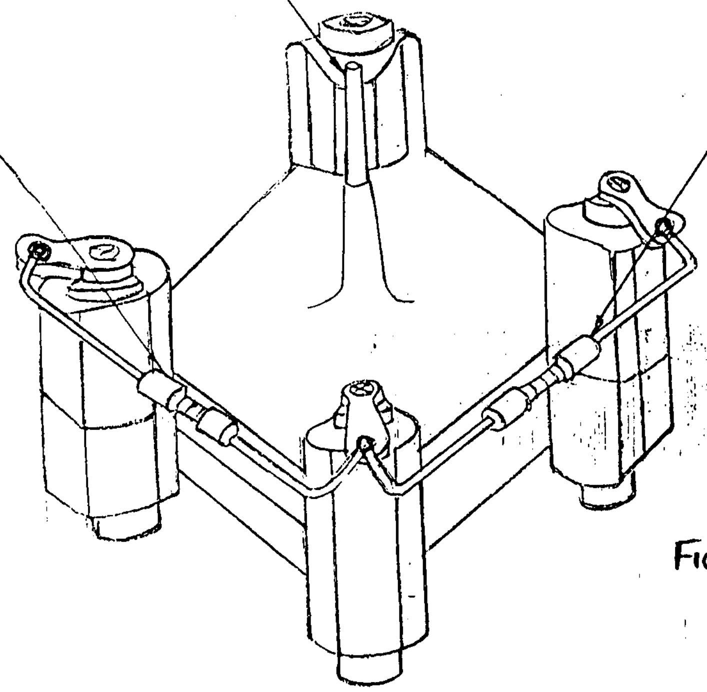


FIGURE:6

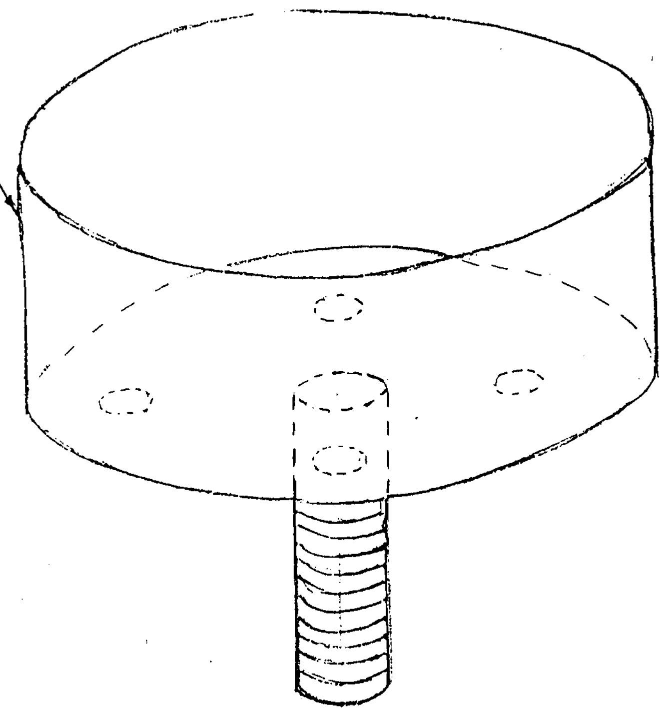


FIGURE:7

TATA INDICA (STD)	DOE FOR FUEL GAUGE CALIBRATION

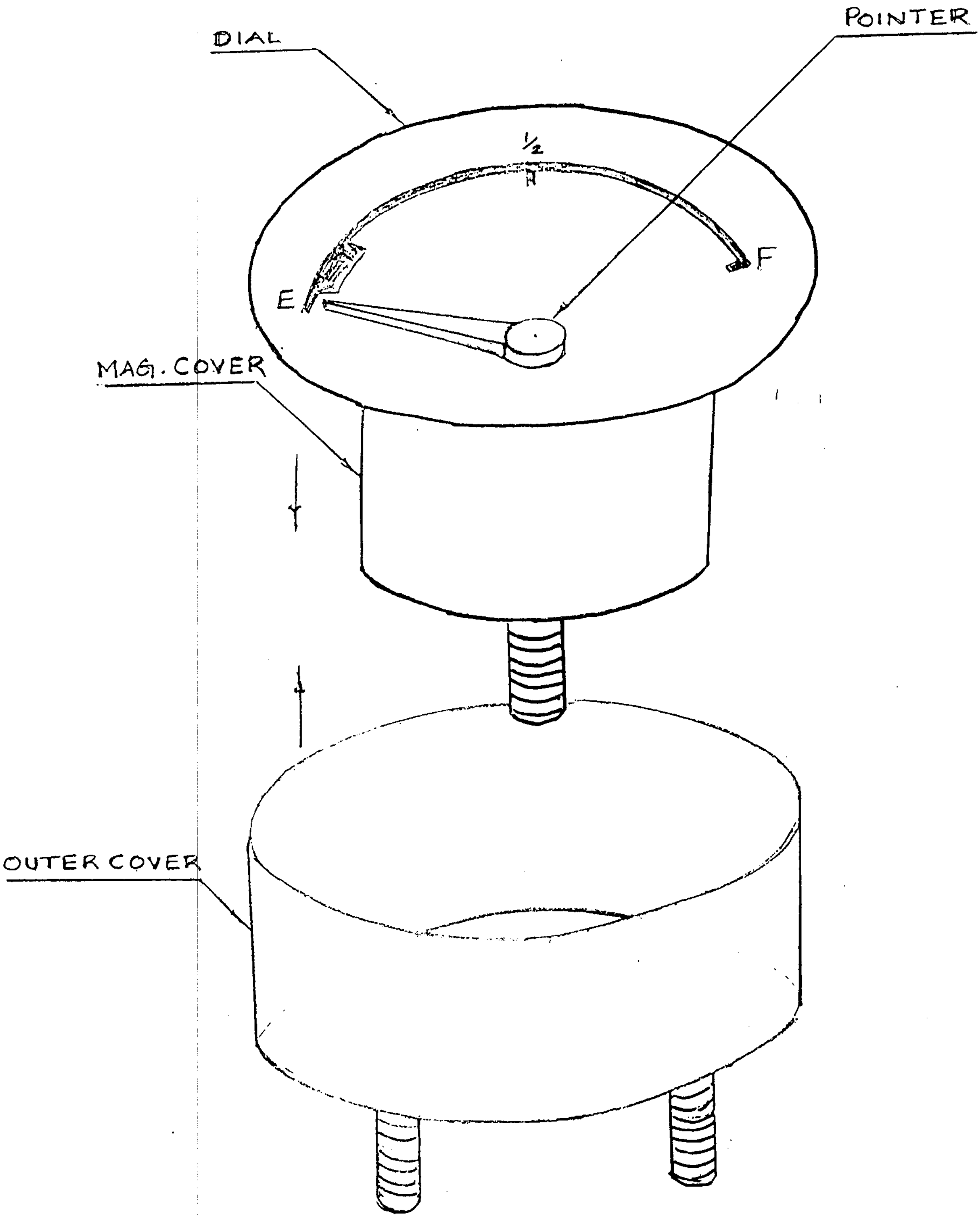
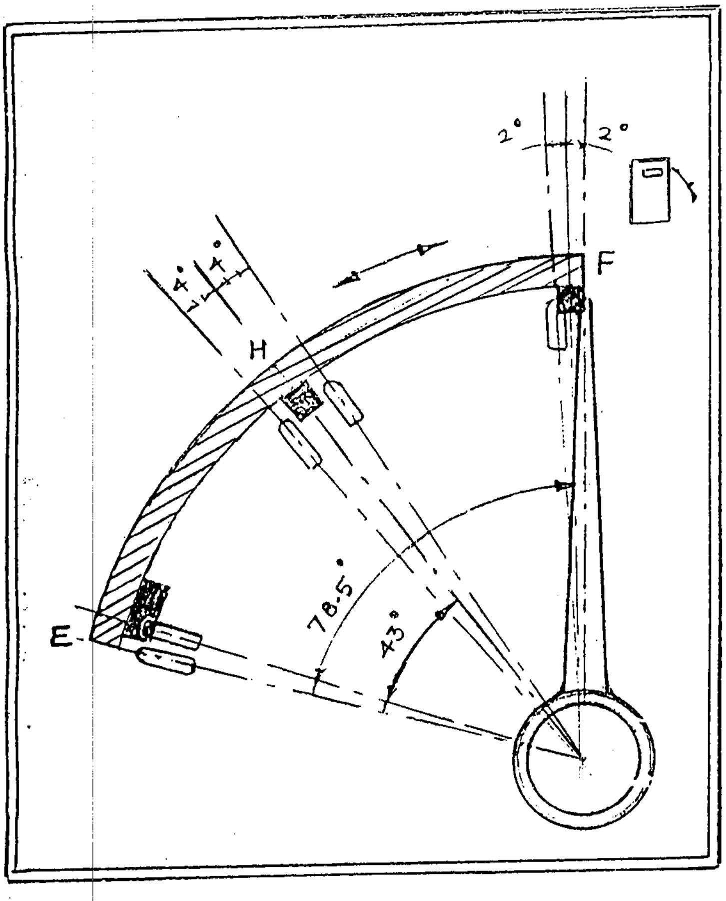


FIGURE : 8



E-H = 43 ± 4°

E-F = 78.5 ± 2°

FIGURE: 9

4.1 Taguchi technique of optimization

The Taguchi technique is divided into three phases namely,

1. Planning phase.

2. Conducting phase.

3. Analysis phase.

<u>Steps involved in doe process</u>

1. Planning phase.

(1) State problem or area of concern.

(2) Select the objective of the experiment

(3) Select the quality characteristics and measurement system.

(4) Select the factors that may influence the selected quality characteristics.

(5) Identify control and noise factors.

(6) Select the levels for the factors.

(7) Select the appropriate orthogonal array.

(8) Select the interactions that may influence the selected quality characteristics.

2. Conducting phase.

(9) Conduct test described by trials in orthogonal array.

3. Analysis phase.

(10) Analyze and interpret results of the experimental trials

(11) Conduct conformation experiment.

I. PLANNING PHASE:

1. State the problem (or) area of concern:

The fuel gauges under go calibration in order to assure their quality after manufacturing. The most of the cases, the gauges undergo adjustments through trial and error method to eliminate the error in the reading. The adjustment results in the fuel gauge to assure its quality. But most of cases the gauges under go rejection due to lack of quality and results in higher rate of rejection

Problem or area of concern:

Product for study: Fuel gauge of a car.

(a) Error in the range setting while calibration.

(b) Trial and error method of adjustment to assure the quality of the fuel gauges.

(c) Results in higher percentage of rejection.

In order to define the problem in quantitative terms, which requires a task aid,

Task aids used:

(1) Product or process test failures.

. (2) Scrap reports.

1. Product or process validation test failures and Scrap report:

A detailed study of the existing situation and the past history of the product, provide clear way to state the problem. A detailed analysis has been made on the test failures of the fuel gauges due to Incorrect reading (ICR) in each month of May, June, July and August 2000. The analyses of the rejection reports provide the impact and effect of discrepancies on the quality.

The succeeding material provides the analyze report in detail.

Rejection Analysis on May 2000:

In the Month of May,

1. No of working days = 27 Days.
2. No of fuel gauges produced = 5277 Nos.
3. No of fuel gauges rejected = 404 Nos.

Percentage of rejection on May = Total number of gauges rejected/ Total number of gauges manufactured.

= 404 / 5277

= 7.65 %

It does not provide the real impact, if the impact of loss is expressed in terms of percentage of rejection. In order to provide a clear vision, the quality loss would provide a clear vision of loss due to variation.

According to Taguchi, convert all the loss in interms of cost, which provide more attention on the quality loss.

Quality loss due to ICR on May 2000:

Cost of fuel gauge	= Rs 129
Percentage of rejection	= 7.65
Cost of mfg. 5277 gauges	= 5277 * 129
Cost of 404 gauges	= 404 * 129
Quality loss	**= Rs 52,110.00**

TABLE: 3 FUEL GAUGE CALIBRATION USING TAGUCHI TECHNIQUE

MODEL: TELCO MINI CAR (STD) TATA INDICA .

GAUGE: ELECTRICAL FUEL GAUGE

REPORT: PERCENTAGE OF REJECTION DUE TO ICR ON JUNE 2000

S.NO	DATE	ICR	OUT PUT
1	1-Jun	6	100
2	2-Jun	10	168
3	3-Jun	8	150
4	5-Jun	9	146
5	6-Jun	10	246
6	7-Jun	9	235
7	8-Jun	8	271
8	9-Jun	9	228
9	10-Jun	16	304
10	12-Jun	22	210
11	13-Jun	10	138
12	14-Jun	17	255
13	15-Jun	11	259
14	16-Jun	18	145
15	17-Jun	13	226
16	19-Jun	9	205
17	20-Jun	12	255
18	21-Jun	11	286
19	22-Jun	4	152
20	23-Jun	5	202
21	24-Jun	6	105
22	26-Jun	9	270
23	27-Jun	4	162
24	28-Jun	3	52
25	29-Jun	6	232
26	30-Jun	8	284
		276	5286

TABLE: 4 FUEL GAUGE CALIBRATION USING TAGUCHI TECHNIQUE

MODEL: TELCO MINI CAR (STD) TATA INDICA .

GAUGE: ELECTRICAL FUEL GAUGE

REPORT: PERCENTAGE OF REJECTION DUE TO ICR ON JULY 2000

S.NO	DATE	ICR	OUT PUT
1	1-Jul	4	100
3	3-Jul	4	77
4	4-Jul	4	132
5	5-Jul	25	259
6	6-Jul	12	210
7	7-Jul	7	133
8	8-Jul	11	218
9	9-Jul	2	40
10	10-Jul	9	104
11	11-Jul	14	303
12	12-Jul	8	220
13	13-Jul	8	170
14	14-Jul	7	232
15	15-Jul	12	247
16	16-Jul	3	110
17	17-Jul	8	234
18	18-Jul	7	132
19	19-Jul	11	248
20	20-Jul	11	257
21	21-Jul	15	205
22	22-Jul	9	227
23	24-Jul	17	294
24	25-Jul	8	210
25	26-Jul	18	126
26	27-Jul	15	235
27	28-Jul	24	298
28	29-Jul	26	250
29	30-Jul	8	125
30	31-Jul	2	102
		299	5271

TABLE: 5 FUEL GAUGE CALIBRATION USING TAGUCHI

MODEL: TELCO MINI CAR(STD)TATA INDICA .

GAUGE: ELECTRICAL FUEL GAUGE

REPORT: PERCENTAGE OF REJECTION DUE TO ICR ON AUGUST

S.NO	DATE	ICR	OUT PUT
1	1-Aug	3	52
2	3-Aug	14	319
3	4-Aug	13	145
4	5-Aug	9	273
5	7-Aug	24	295
6	8-Aug	11	297
7	9-Aug	9	275
8	10-Aug	11	301
9	11-Aug	15	146
10	12-Aug	18	245
11	13-Aug	6	121
12	16-Aug	16	294
13	17-Aug	10	250
14	18-Aug	12	314
15	19-Aug	24	292
16	21-Aug	14	160
17	22-Aug	5	192
18	23-Aug	12	172
19	24-Aug	13	150
20	25-Aug	7	112
21	26-Aug	6	120
	TOTAL	171	3327

Rejection Analysis on June 2000:

In the Month of May,

1. No of working days = 26 Days.
2. No of fuel gauges produced = 5286 Nos.
3. No of fuel gauges rejected = 276 Nos.

Percentage of rejection on May

= 276 / 5286

= 5.22 %

Quality loss due to ICR on June 2000:

Cost of fuel gauge	= Rs 129
Percentage of rejection	= 5.22
Cost of mfg. 5277 gauges	= 5286 * 129
Cost of 404 gauges	= 276 * 129
Quality loss	**= Rs 35,601.00**

Rejection Analysis on July 2000:

In the Month of May,

1. No of working days = 30 Days.
2. No of fuel gauges produced = 5498 Nos.
3. No of fuel gauges rejected = 309 Nos.

Percentage of rejection on May

= 309 / 5498

= 5.62 %

Quality loss due to ICR on July 2000:

Cost of fuel gauge	= Rs 129
Percentage of rejection	= 5.62
Cost of mfg. 5277 gauges	= 5498 * 129
Cost of 404 gauges	= 309 * 129
Quality loss	**= Rs 39,859.00**

Rejection Analysis on August 2000:

In the Month of May,

1. No of working days = 21 Days.
2. No of fuel gauges produced = 3397 Nos.
3. No of fuel gauges rejected = 171 Nos.

Percentage of rejection on May

= 171 / 3327

= 5.13 %

Quality loss due to ICR on August 2000:

Cost of fuel gauge	= Rs 129
Percentage of rejection	= 5.13
Cost of mfg. 5277 gauges	= 3327 * 129
Cost of 404 gauges	= 171 * 129
Quality loss	**= Rs 21,017.00**

Total Quality Loss from May to August = 52,110.00 + 35,601.00 + 39,859 + 22,017.00

= Rs 1,49,587.00

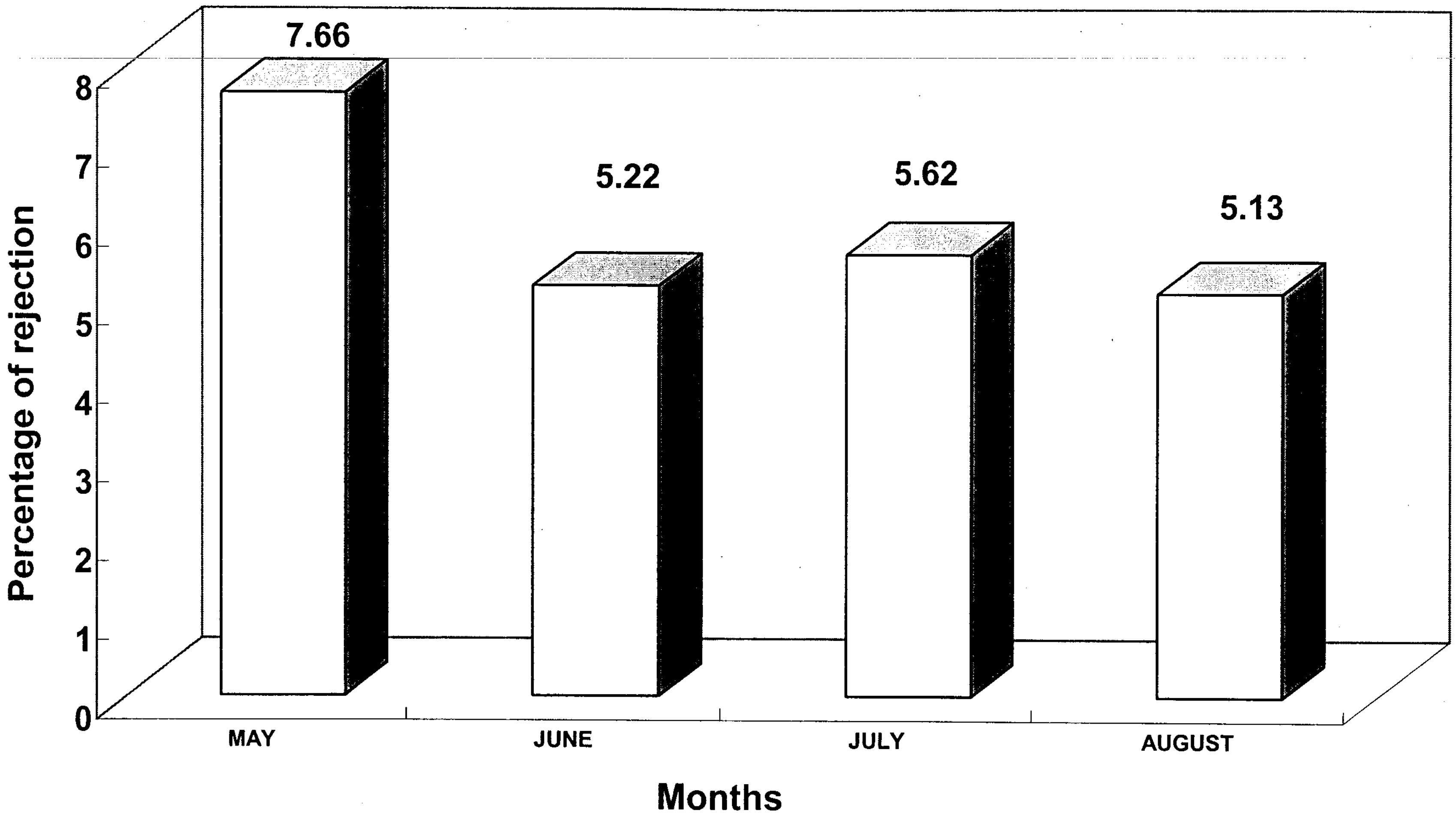


FIGURE: 10 PERCENTAGE OF REJECTION

2. The objective of the experiments:

(1) Eliminating the error in the fuel gauge.
(2) Eliminating the trial and error method of adjustment.
(3) Optimizing the process parameters and response.
(4) Reducing the percentage of rejection.

Task aids used:

Internal Customer Requirements:

The people who are involved in the entire manufacturing were called internal customer. The people in the planning are the customer to the purchase. The people in the manufacturing are the customer to the planning. The people in the sales are the customer to the Sales etc., hence assemblies are the customer to the proceeding assemblies like wise the people involved in the calibration are the customer to assembly and subassembly of previous stage of assembly. So every section of the assembly requires good product from the proceeding activity.

3. Selection of the quality characteristics and measurement system:

The characteristics that effect the response are considered as quality characteristics.

The objectives of the experiments are the quality characteristics.

Quality characteristics:
(1) Error in the range setting.
(2) Crude method of adjustment.

Measurement system:
(1) instruments & gauges
(2) Visual inspection.

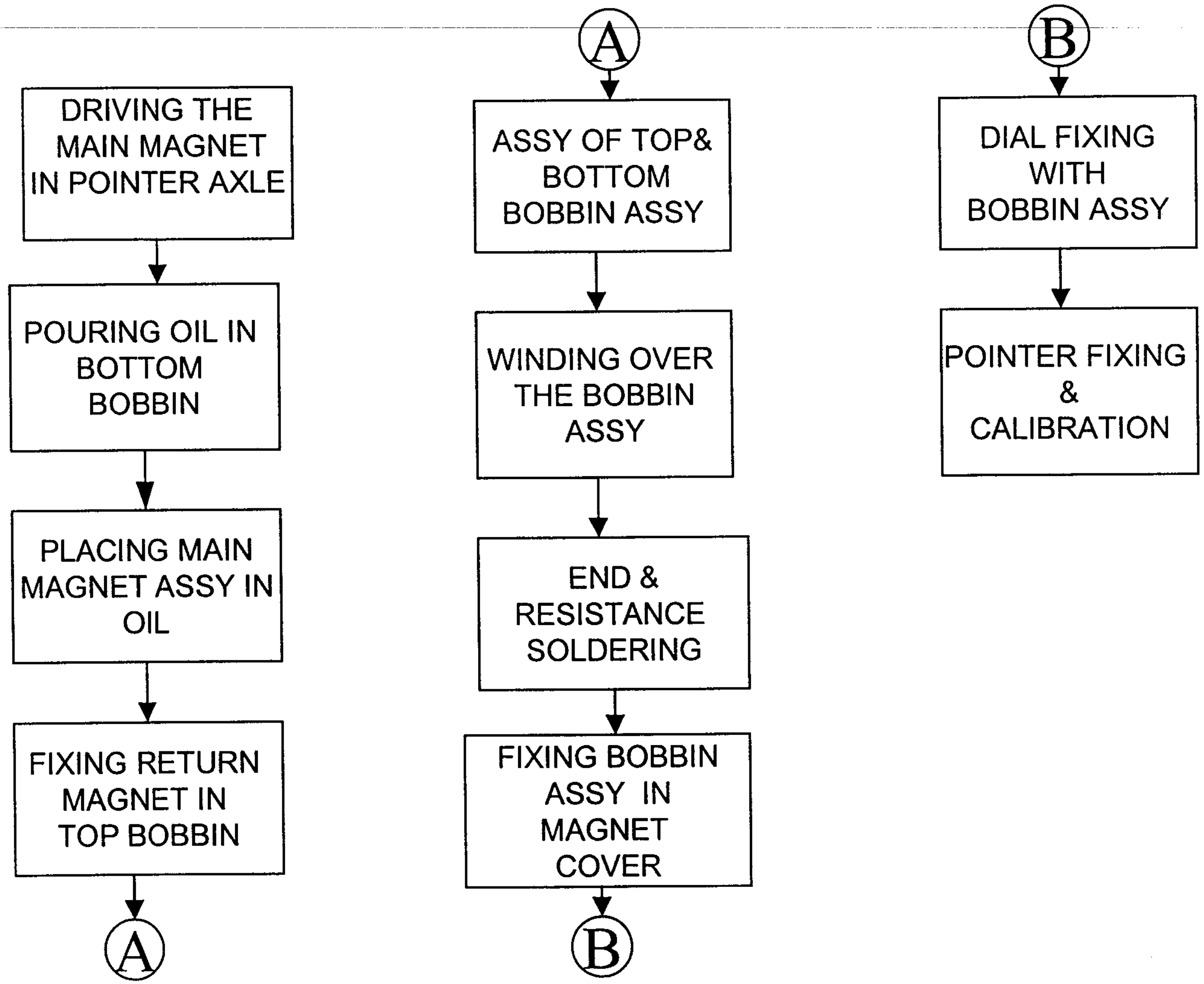


FIGURE: 12 PROCESS FLOW CHART FOR GAUGE MANUFACTURING

Task aids used:

Process flow diagram.

Process flow diagram:

The process flow diagram provides a diagrammatic view of processes involved in the fuel gauge manufacturing in step by step flow as shown in the figure: 12

4. Selection of factors that may influence the selected quality characteristics:

The response of the pointer of the fuel gauge depends upon number of factors (or) parameters involved in the fuel gauge. Hence response of the pointer depends on each of the parameters of the system. If any one of the parameter goes out of specification have an impact on the response of the pointer. Ultimately the response of the pointer is directly proportional to parameter specification of the components. Among all the parameters involved in the system, some of the parameters have least effect on the response, some of the parameters have more effect on response.

Reason for the error in the range setting:

To trace the reason for the error in the range setting a methodology is followed called "Reverse Engineering".

4.2 Reverse Engineering:

"Reverse Engineering" is a technique in which the input of a system can be obtained from out put of the system. Some cases the input parameters specification can be obtained from the output response of the system. In this case the output of the fuel gauge is the response of the pointer, so based on the response the input parameter specification can be obtained.

Steps involved in the Reverse Engineering:

To start with the analysis, twenty four fuel gauges were chosen. In that, twelve gauges were of good working condition i.e., gauges were assured that there was no error in the range setting. Remaining twevel gauges were found to be in improper working condition i.e., assured of error in the calibration.
These twenty four gauges were exploded and their individual parameters were measured and tabulated as shown in the table: 6 and table: 7

Inference on Reverse engineering:

After performing the analysis, it is found that the following parameters may contribute to the output response.

1. Main magnet permeability.
2. Main magnet run out.
3. Main magnet face out.
4. Main magnet driving height.
5. Winding turns.
6. Winding resistance.
7. Quantity of oil.
8. Return magnet permeability.
9. Weight of pointer.

It was found that among all the parameters the following parameters are not exactly matching with the specification given in the production drawing

- Winding resistance (I-II) in Ohms.
- Winding resistance (II-III) in Ohms
- Main magnet permeability in gauss.
- Return magnet permeability in Ohms.
- Quantity of silicon oil in milligrams.

TABLE: 6 FUEL GAUGE CALIBRATION USING TAGUCHI TECHNIQUE

REVERSE ENGINEERING

MODEL : TATA INDICA FUEL GAUGE
STATUS : WITH ADJUSTMENT
NO OF SPECIMEN :12NOS

S NO	PARAMETERS	TARGET	SPE1	SPE 2	SPE 3	SPE 4	SPE 5	SPE 6	SPE 7	SPE 8	SPE 9	SPE 10	SPE 11	SPE 12	AVERAGE	STATUS
1	Pointer weight	1.16+/-0.1	1.1615	1.1665	1.165	1.152	1.158	1.1685	1.1475	1.164	1.1585	1.155	1.151	1.1635	1.16	OK
3	Run out	< 0.15mm	0.1	0.12	0.05	0.11	0.06	0.12	0.07	0.13	0.09	0.17	0.17	0.15	0.11	OK
4	Face out	< 0.15mm	0.09	0	0.07	0.14	0.07	0.09	0.04	0.13	0.1	0.18	0.13	0.11	0.10	OK
5	Driving height	6.5+ / - 0.1mm	6.47	6.52	6.55	6.6	6.48	6.5	6.59	6.6	6.55	6.57	6.52	6.6	6.55	OK
6	**Res of resistor**															
	Res of resistor(Y)	82+/- 5 Ohms	82.1	82.3	82	82.6	82.3	82.7	82.2	82.6	82.3	82.1	82.2	82.4	82.32	OK
	Res of resistor	47+/- 5 Ohms	47.5	46.5	47.4	47.9	47.8	47.9	47.4	47.5	47.9	48.3	46.6	47.6	47.53	OK
7	**Winding turns**															
	First winding	260 + / - 10 Ts	260	265	259	258	260	251	260	260	260	300	260	285	265	OK
	Secand winding	385 + / -10 Ts	385	390	385	395	388	385	387	388	386	375	375	385	385	OK
	Third winding	550 + / -10 Ts	555	560	544	548	551	553	549	550	550	550	550	550	551	OK
	Winding resistance															
9	Winding I - II	**	54.3	54.7	53.2	52.8	53.5	53.2	53.1	54.2	53.3	55.2	52.3	55.1	53.74	NOT OK
10	Winding II - III	**	50.4	51	50.1	49.8	50.4	50.9	50.6	50.3	50.5	50	49.9	51.1	50.42	NOT OK
11	weight of oil	130 +/- 10 mg	98	100	94.5	87	98	102.5	98	101	87	96.5	94.5	95	96.0	NOT OK
	wgt of magnet assy	1.6+/-0.1	1.6805	1.691	1.6825	1.6885	1.7065	1.708	1.689	1.7	1.662	1.6665	1.7095	1.695	1.69	OK
12	**Main magnet**															
	North (N)	900 + / - 50 ga	490	495	504	460	492	486	493	460	502	499	495	490	489	NOT OK
	South (S)	900 + / - 50 ga	482	504	490	470	483	501	497	484	495	479	504	502	491	NOT OK
13	**Return magnet**															
	North (N)	300 + / - 20ga	156	153	150	143	134	116	158	167	161	185	193	181	158	NOT OK
	South (S)	300 + /- 20ga	147	162	162	174	161	144	150	142	150	165	154	146	155	NOT OK

TABLE: 7 FUEL GAUGE CALIBRATION USING TAGUCHI TECHNIQUE

REVERSE ENGINEERING

MODEL : TATA INDICA FUEL GAUGE
STATUS : WITH OUT ADJUSTMENT
NO OF SPECIMEN :12NOS

S NO	PARAMETERS	TARGET	SPE1	SPE 2	SPE 3	SPE 4	SPE 5	SPE 6	SPE 7	SPE 8	SPE 9	SPE 10	SPE 11	SPE 12	AVERAGE	STATUS
1	Pointer weight	1.16+/-0.1	1.1575	1.1385	1.1665	1.164	1.151	1.166	1.148	1.1645	1.1518	1.151	1.15	1.1575	1.156	OK
3	Run out	< 0.15mm	0.13	0.07	0.03	0.05	0.15	0.17	0.04	0.1	0.15	0.07	0.12	0.06	0.10	OK
4	Face out	< 0.15mm	0.04	0.05	0.07	0.02	0.1	0.14	0.04	0.15	0.14	0.1	0.05	0.07	0.08	OK
5	Driving height	6.5+ / - 0.1mm	6.43	6.45	6.53	6.57	6.47	6.47	6.5	6.63	6.67	6.62	6.6	6.45	6.5	OK
6	Res of resistor															
	Res of resistor(Y)	82+/- 5 Ohms	82.5	82.8	82.5	82.2	82.5	82.6	81.8	82.4	81.9	82.2	81.8	82.1	82.28	OK
	Res of resistor	47+/- 5 Ohms	47.3	48	47.8	47.3	46.8	47.1	47.5	48	47.1	47.2	46.7	47.3	47.34	OK
7	Winding turns															
	First winding	260+/- 10 Ts	260	262	265	265	265	260	260	260	255	275	260	255	262	OK
	Secand winding	385 +/-10 Ts	390	386	385	385	380	390	395	390	395	395	390	395	390	OK
	Third winding	550+/-10 Ts	555	555	550	560	570	570	555	550	550	565	550	555	557	OK
	Winding resistance															OK
9	Winding I - II	**	54.5	54.4	53.3	53.9	54.2	54.3	54	53.6	53.9	54.8	55.5	55.1	54.29	NOT OK
10	Winding II - III	**	51.4	51.3	50.3	51	51	50.8	50.5	50.6	50.6	50.6	51	50.7	50.82	NOT OK
11	weight of oil	130 +/- 10 mg	101	90.5	101	101	100	92	95	89	94.5	94.5	106.5	141	100.50	OK
	wgt of magnet assy	1.6+/- 0.1	1.7085	1.7255	1.694	1.6895	1.7	1.662	1.6865	1.6885	1.7305	1.7165	1.7125	1.686	1.70	OK
12	Main magnet															
	North (N)	900+/- 50 ga	505	505	504	487	501	506	504	511	507	507	502	501	503	NOT OK
	South (S)	900+/- 50 ga	505	504	507	500	507	507	506	509	484	516	490	508	504	NOT OK
13	Return magnet															
	North (N)	300+/-20ga	146	139	148	117	154	164	138	177	125	172	159	158	150	NOT OK
	South (S)	300+/-20ga	144	137	159	114	171	133	154	177	105	175	190	149	151	NOT OK

5. **Identifying control and noise factors:**

Control factors:

Control factors are those factors that a manufacturer can control in the design of a product or in the design of a process or during a process.

Noise factors:

Noise factors are those things that a manufacturer cannot or wishes not to control for cost reasons. Noise factors may be controlled temporarily during an experiment, but in an actual production or customer environment may not or cannot be controlled at all.

Noise factor are either too expensive or impossible to control on a continuous basis, the focus of the experiment should be on the effects of the true control factors.

Description	**Control factors**	**Noise factors**
Main magnet & Return magnet	Magnet design, Material specification	Chemical composition Material batch variation Ambient temperature Humidity
Winding	Design, Winding method Winding tension, number of turns	Specific resistance Dia of wire Batch to batch variation
Quantity of oil	Weight of oil Viscosity of oil	Operator's performance Method of usage of Equipment

6. Selection of levels for the factors:

The selection of levels for each factor decides the number of experiments to be conducted

Task aids used:

1. Product or process technical experts.
2. Product or process specification or operating limits.

Product or process technical experts:

Selection of levels for the factor basically depends upon the type of the system or product or manufacturing. The fuel gauge is more sensitive to the variation since it is basically operating on electrical principle. And hence, controlling parameter levels are difficult. So the selection of levels were limited to two. Hence expert advised to select two levels for the experiment.

Product specification (or) operating limits:

In addition to the above, fixing of levels should have a consistency while experimentation, by referring specification it is advisable to only two levels instead of more levels. Because repeatability will not be there in case of having more than two levels. Hence based on the drawing specification also the levels for the experiment is chosen as two.

S.NO	PARAMETERS	UNIT	MIN LEVEL	MAX LEVEL
1	Winding resistance (I-II)	Ohms	53.3	54.3
2	Winding resistance (II-III)	Ohms	49.8	50.8
3	Main magnet permeability	Gauss	460	505

7. Selection of appropriate orthogonal arrays:

Orthogonal array is table, which provides the combinations of parameters, and their levels with in which the experiment is to be conducted.

Hence the selection of orthogonal array depends upon the number of parameters and their levels.

Number of parameters: three namely,

1. Winding resistance (I-II)
2. Winding resistance (II-III)
3. Main magnet permeability.

Number of levels: two, namely

1. Min level
2. Max level.

In order to select the number of experiments to be conducted is given by the formula,

$$2^k$$

where 'k' denotes number of parameters.

Number of experiments to be conducted = $\mathbf{2}^3 = 8$

Task aid used:

Orthogonal array selection table

For, number of parameters = 3 and number of levels = 2 the orthogonal array is shown in the table: 8

TABLE:8
ORTHOGONAL ARRAY

EXPERIMENT	TREATMENT FOR			OBSERVED RESPONSE
	A	B	C	
1	-1	-1	-1	Y1
2	-1	-1	1	Y2
3	-1	1	-1	Y3
4	-1	1	1	Y4
5	1	-1	-1	Y5
6	1	-1	1	Y6

8. Selection of factors that may influence the selected quality characteristics:

All the selected parameters have an influence on the selected quality characteristics. The degree of influence on the quality characteristics may vary parameter to parameter.

Some parameters have greater influence on the quality characteristics. Some parameters have less influence on the quality characteristics, hence considering the individual parameter's influence on the quality characteristics does not provide a real picture to optimize the response.

To avoid such type of controversy, study of interactions of parameters and their impact on quality characteristics does provide a clear vision by taking into consideration of interaction, the three of A, B and C A are combined as AB, AC and BC and these combined effects are studied. And their relationship on the response was analyzed after conducting the experiments.

9. Conducting test described by trials in orthogonal array:

After performing the planning phase, the conducting phases are carried out as described in the orthogonal array table: 9.

In order to consider the noise factors, eight experiments were carried out in the random sequence. While performing the experiment, the noise factors have greater impact on the response and fixing the parameters level.

For example,

In the morning, while starting the production operator performs his work in an efficient manner than in the afternoon or in the evening. Similarly, the ambient temperature may vary time to time results influence while conducting the experiments.

Hence the experiments were conducted in a random order in order to consider the noise factor's influence on response. Like wise the experiments were

FUEL GAUGE CALIBRATION USING TAGUCHI TECHNIQUE

TABLE: 9A

SPECIFICATION	MIMIMUM	NOMINAL	MAXIMUM
EMPTY	2 Deg	0 Deg	2 Deg
EMPTY - HALF	39 Deg	43 Deg	47 Deg
EMPTY - FULL	76.5 Deg	78.5 Deg	80.5 Deg

PARAMETERS	UNITS	MIN LEVEL	MAX LEVEL
MAIN MAGNET	GAUSS	460	505
WINDING I-II	OHMS	53.3	54.3
WINDING II-III	OHMS	49.8	50.8

TABLE: 9 ORTHOGONAL ARRAY

EXPERIMENT	TREATMENT FOR			OBSERVED RESPONSE
	A	B	C	
1	-1	-1	-1	Y1
2	-1	-1	1	Y2
3	-1	1	-1	Y3
4	-1	1	1	Y4
5	1	-1	-1	Y5
6	1	-1	1	Y6
7	1	1	-1	Y7
8	1	1	1	Y8

conducted and their response are plotted in the table: 9. The fuel gauges has two responses namely, half and full position in terms of degree in the
table : 9

For example,

Ex no 1

The parameter A is fixed in the Min level	= 53.3 Ohms.
The parameter B is fixed in the Max level	= 49.8 Ohms.
The parameter C is fixed in the Min level	= 460 Gauss.

The experiment trial were conducted and the response of half position and full position is recorded,

Response - half position = 43.5^{0}

Response – full position = 76.5^{0}

Hence the experiments are conducted in a random order in order to consider the noise factor's influence on the response.

10. Analysis and interpretation of results of the experimental trials:

After conducting all the experiments the response are tabulated in the orthogonal array table. In order to know the pattern of variation in the observed response, the observed data are transformed in to a graphical form as shown in the figure: 14 for half position Similarly the response of full position also displayed in the figure: 15

From the figure: 14 and figure: 15, It was found that the responses are scattered in both min and Max level of the specification of response as shown in the table 9 A.

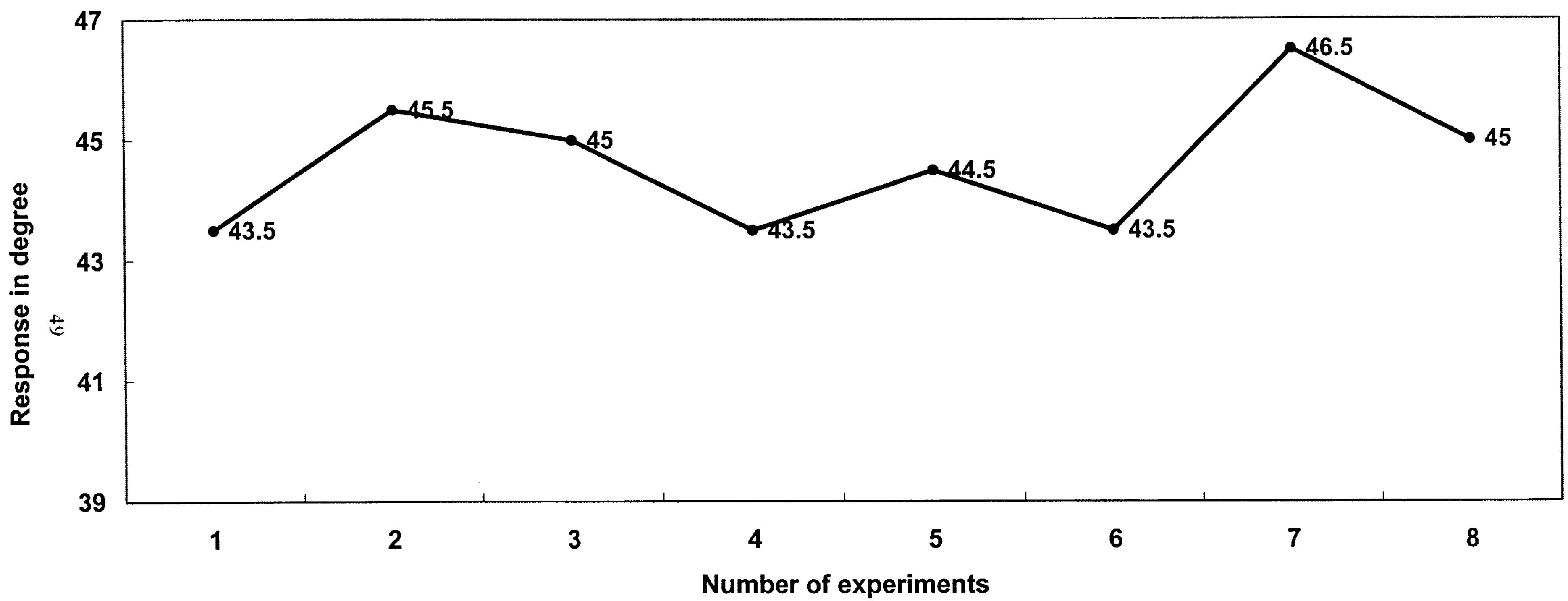


FIGURE: 14 RESPONSE ANALYSIS (HALF POSITION)

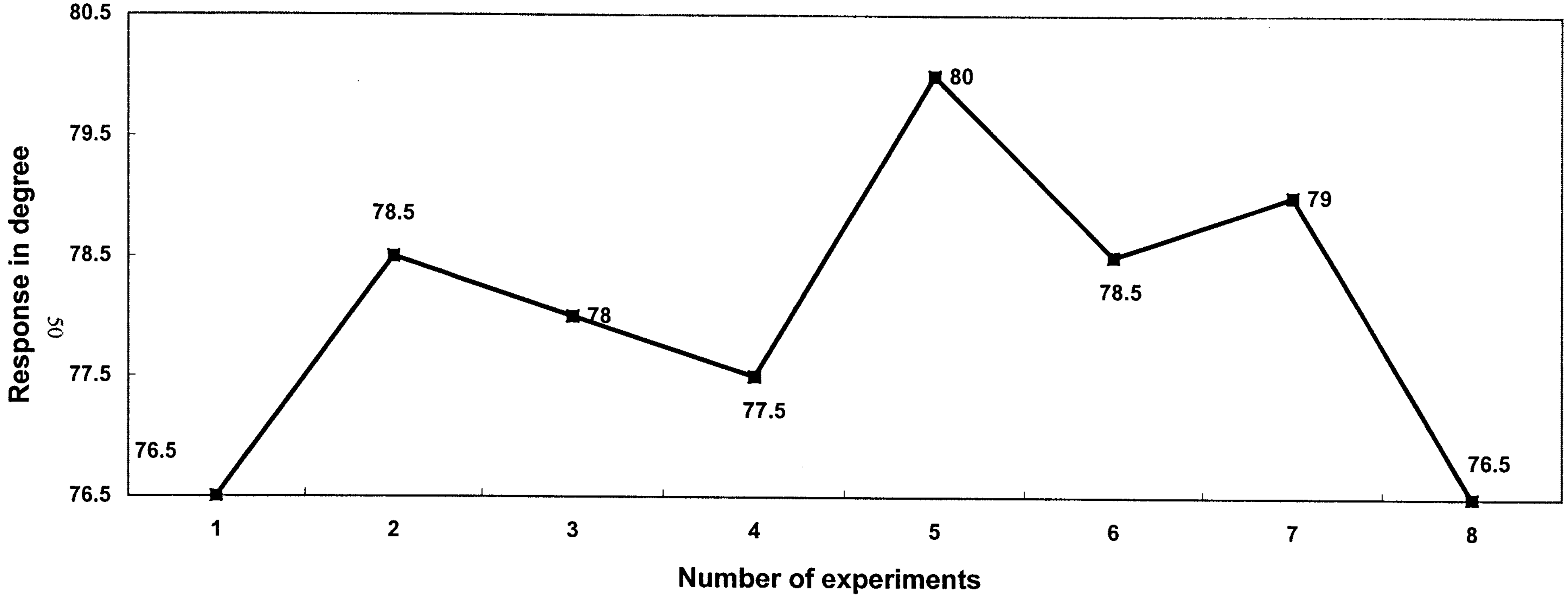


FIGURE: 15 RESPONSE ANALYSIS (FULL POSITION)

OPTIMIZATION OF PARAMETERS AND THEIR RESPONSE: (By considering main effect of parameters on response for half position)

After performing the response analysis in the above, the observed responses are plotted in a table called "Response Table" as shown in the table : 10. "response table is a table, which provides the estimated main effect of parameters on response". This table is designed for estimating and calculating the optimized parameters and their optimized response of the given system of study.

The table: 10 meant for calculating optimized response by considering only the main effect of individual parameter on response. Based on the procedure given in the response table, the observed responses are plotted for half and full position.

Optimization of response (H):

The observed responses are transformed into "response table". The values of the responses are plotted by performing procedures given in the response table: 10.

The objective of the experiment is to eliminate the error and to optimize the response. Hence the objective function is taken as minimization. To optimize the response a formula is given in the table: 11

Optimization of response for Half position:

Optimized Response (H) Y bar $_{min}$ = Y bar + (A_1bar – Y bar) + (B_1 bar - Y bar) + (C_1 bar – Y bar)

Where, Y bar $_{min}$ - Optimized response for half position.

Y bar - Average of all response for half position.

A_1bar - Average of response corresponding to A_1.

B_1 bar - Average of response corresponding to B_1

TABLE: 10 FUEL GAUGE CALIBRATION USING TAGUCHI TECHNIQUE

PRODUCT : TATA INDICA FUEL GAUGE

RESPONSE TABLE FOR A THREE - FACTOR EXPERIMENT

RANDOM NO	TRIAL	OBSERVED RESPONSE	A		B		C	
			-1	1	-1	1	-1	1
	1	Y1	Y1	*	Y1	*	Y1	*
	2	Y2	Y2	*	Y2	*	*	Y2
	3	Y3	Y3	*	*	Y3	Y3	*
	4	Y4	Y4	*	*	Y4	*	Y4
	5	Y5	*	Y5	Y5	*	Y5	*
	6	Y6	*	Y6	Y6	*	*	Y6
	7	Y7	*	Y7	*	Y7	Y7	*
	8	Y8	*	Y8	*	Y8	*	Y8
TOTAL		(SUM OF OBSERVATION IN COLUMNS ABOVE GOES HERE)						
NO OF DATA VALUES		8	4	4	4	4	4	4
AVERAGE		Y BAR	A BAR_1	A BAR_2	B BAR_1	B BAR_2	C BAR_1	C BAR_2
EST. MAIN EFFECT			A BAR_1 - A BAR_2		B BAR_1 - B BAR_2		C BAR_1 - C BAR_2	

TABLE: 11 FUEL GAUGE CALIBRATION USING TAGUCHI TECHNIQUE

PRODUCT FUEL GAUGE

SPEC	MINIMUM	NOMINAL	MAXIMUM
E - H	39^{o}	43^{o}	47^{o}

PARAMETERS	NOTATION
WINDING (I-II)	A
WINDING (II - III)	B
MAGNET	C

RESPONSE TABLE ALONG WITH MAIN EFFECT (FOR HALF POSITION)

RANDOM NO	TRIAL	OB.RESPONSE (Degree)	A		B		C	
			1	2	1	2	1	2
4	1	43.5	43.5	*	43.5	*	43.5	*
1	2	43.5	43.5	*	43.5	*	*	43.5
8	3	45	45	*	*	45	45	*
5	4	44.5	44.5	*	*	44.5	*	44.5
6	5	43.5	*	43.5	43.5	*	43.5	*
3	6	45	*	45	45	*	*	45
2	7	45.5	*	45.5	*	45.5	45.5	*
7	8	46.5	*	46.5	*	46.5		46.5
TOTAL		357	176.5	180.5	175.5	181.5	177.5	179.5
NO OF DATA VALUE		8	4	4	4	4	4	4
AVERAGE		44.63	44.13	45.13	43.88	45.38	44.38	44.88
EST.MAIN EFFECT			0.975		1.5		0.5	

Y BAR = Y BAR+ (A BAR1 - Y BAR) + (B BAR1- Y BAR) + (C BAR1 - Y BAR)

OPTIMIZED RESPONSE (H) - (Y BAR) 43.1 Degree

Optimized parameters are selected from the figure(16)

WINDIING (I- II)	A1	53.3 Ohms
WINDING (II- III)	B1	49.8 Ohms
MAGNET	C1	460 Gauss

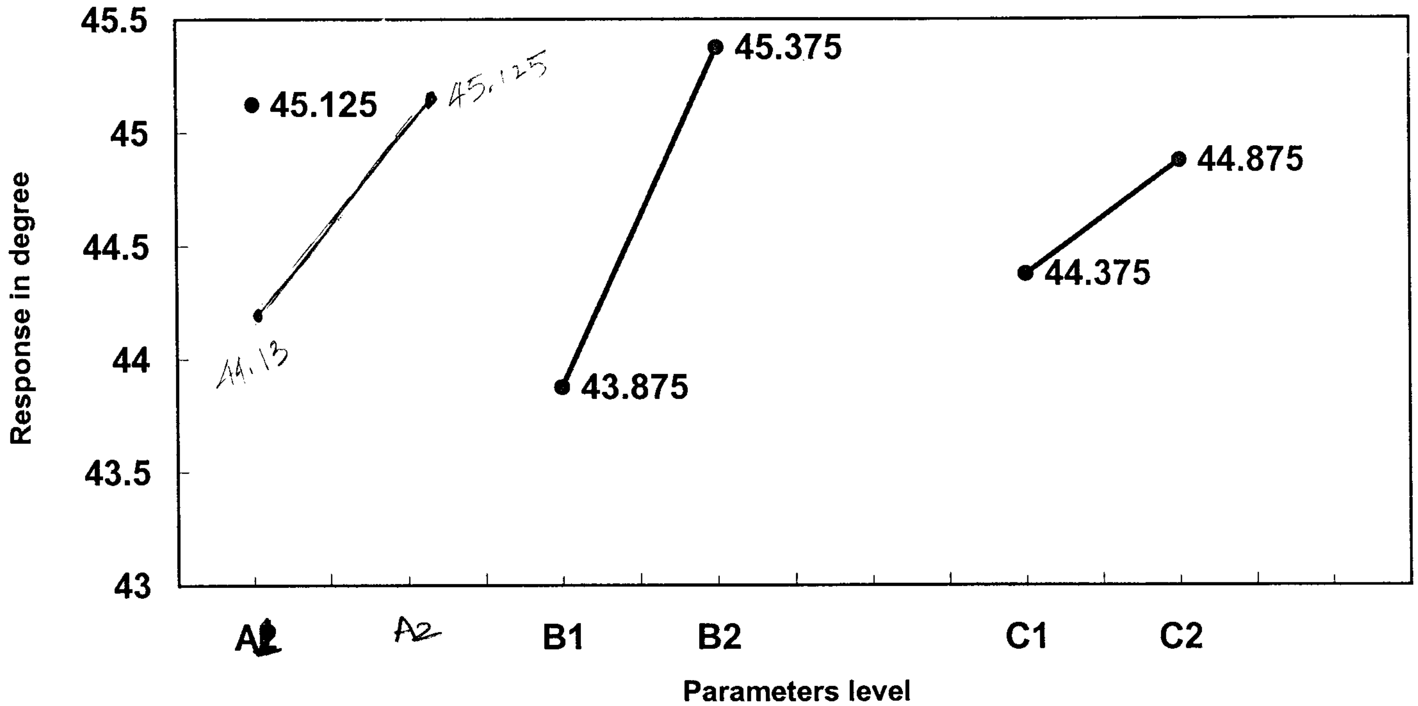


FIGURE: 16 MAIN EFFECT OF PARAMETERS ON RESPONSE
(HALF POSITION)

C_1 bar - Average of responses corresponding to C_1.

Y bar = 44.63, A_1 bar = 44.13, B_1 bar = 43.88, C_1 bar = 44.88

Y bar = 44.63 + (44.13 – 44.63) + (43.88 – 44.63) + (44,88 – 44.63)

= 43.1 Degree.

Optimized response for half position (H) = 43.1 Degree

Optimization of parameters:

From the table: 11 the estimated " Main effect of parameters on response" is plotted in terms of graphical form as shown in the figure: 16.

(a) Estimated main effect of "A" on response = 0.975^0

(b) Estimated main effect of "B" on response = 1.5^0

(c) Estimated main effect of "C" on response = 0.5^0

To optimize the parameters a dotted line is drawn in the figure: 16 from the response graphs A, B and C, such that, the value (or) point closer to the optimized response value of 43.1 degree, is taken so from the graph, it was found that, the dotted line meets at A_1, $B_1$and C_1 coordinate on the X axis.

Hence the optimized response, is given by,

(1) Winding resistance (I-II) = A = A1 = 53.3 Ohms.

(2) Winding resistance (II –III) = B = B1 = 49.8 Ohms.

(3) Main magnet permeability = C = C1 = 460 Gauss.

TABLE: 12 FUEL GAUGE CALIBRATION USING TAGUCHI TECHNIQUE

PRODUCT	FUEL GAUGE	SPEC	MINIMUM	NOMINAL	MAXIMUM
		E - F	76.5°	78.5°	80.5°

RESPONSE TABLE ALONG WITHMAIN EFFECT (FOR FULL POSITION)

RANDOM NO	TRIAL	OB.RESPONSE (Degree)	A		B		C	
			1	2	1	2	1	2
4	1	77.5	77.5	*	77.5	*	77.5	*
1	2	76.5	76.5	*	76.5	*	*	76.5
8	3	76.5	76.5	*	*	76.5	76.5	*
5	4	80	80	*	*	80	*	80
6	5	78.5	*	78.5	78.5	*	78.5	*
3	6	78	*	78	78	*	*	78
2	7	78.5	*	78.5	*	78.5	78.5	*
7	8	79	*	79	*	79		79
TOTAL		624.5	310.5	314	310.5	314	311	313.5
NO OF DATA VALUE		8	4	4	4	4	4	4
AVERAGE		78.063	77.625	78.5	77.625	78.5	77.75	78.375
EST.MAIN EFFECT			0.875		0.875		0.625	

Y BAR = Y BAR+ (A BAR1 - Y BAR) + (B BAR1- Y BAR) + (C BAR1 - Y BAR)

OPTIMIZED RESPONSE (F)Y BAR = 76.9 DEGREE

OPTIMIZATION OF PARAMETERS AND THEIR RESPONSE: (By considering the interaction of parameters on response for full position)

The observed responses (F) are transformed into response table as shown in the table: 12. The values of observed response are entered, by performing the procedures given in the response table. The objective function is taken as minimization, therefore the optimized response is obtained by a formula given in the table: 12.

Optimization of response for full position:

Optimized Response (H) $\bar{Y}_{min}$ = Y bar + (A_1bar – Y bar) + (B_1 bar - Y bar) + (C_1 bar – Y bar)

Where, $\bar{Y}_{min}$ - Optimized response for half position.

Y bar - Average of all response for half position.

A_1bar - Average of response corresponding to A_1

B_1 bar - Average of response corresponding to B_1

C_1 bar - Average of responses corresponding to C_1

Y bar = 78.06, A_1 bar = 77.625, B_1 bar = 77.625, C_1 bar = 77.75

Y bar = 78.06 + (77.625 – 78.06) + (77.625 – 78.06) + (77.75 – 78.06)

= 76.9 Degree.

Optimized response for half position (H) = 76.9 Degree

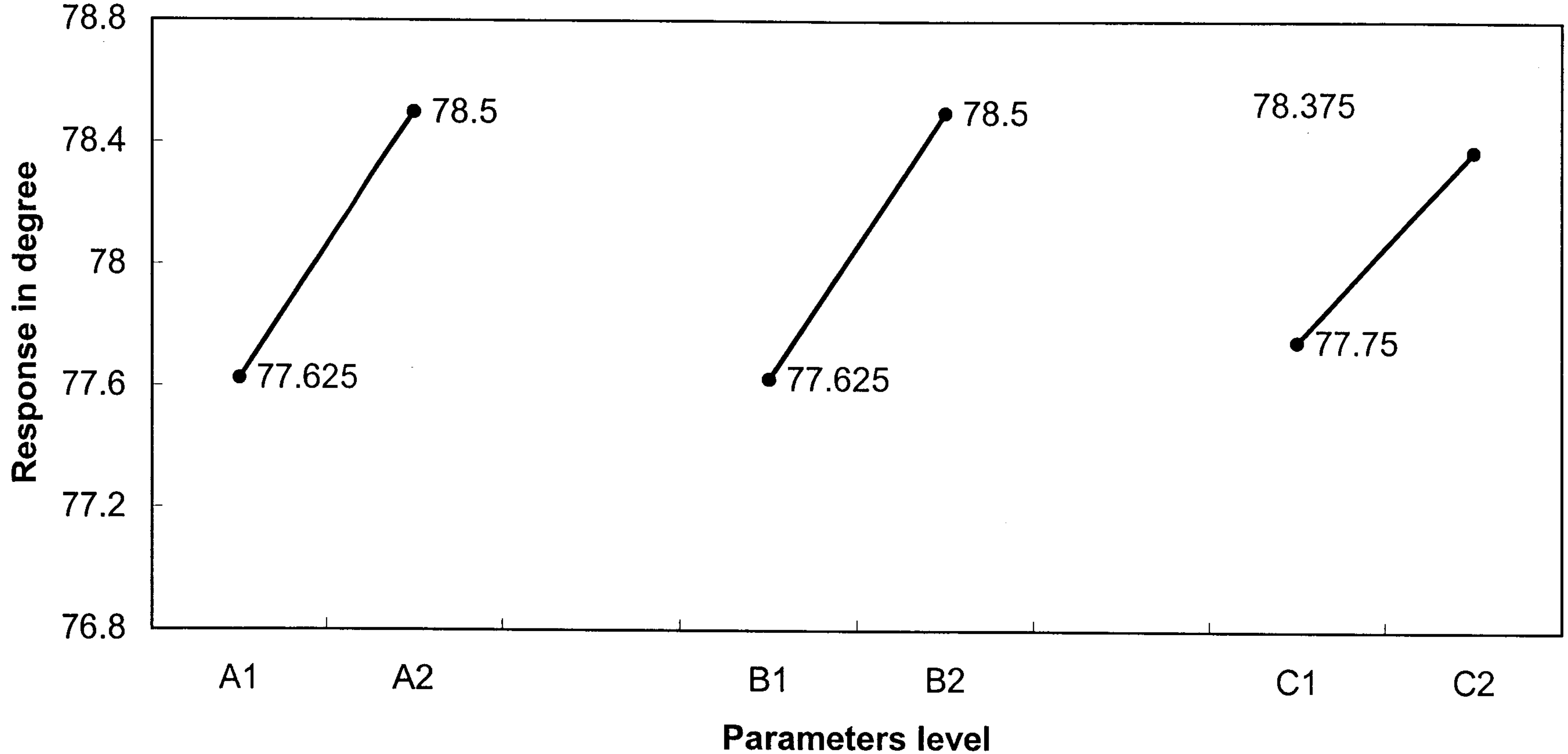


FIGURE: 17 MAIN EFFECT OF PARAMETERS ON RESPONSE (FULL POSITION)

Optimization of parameters:

From the table: 12 the estimated "main effects of parameters on response" are plotted interms of graphical form as shown in the figure: 17.

(a) Estimated main effect of "A" on response = 0.875^{0}

(b) Estimated main effect of "B" on response = 0.875^{0}

(c) Estimated main effect of "C" on response = 0.625^{0}

To optimize the parameters a dotted line is drawn in the figure: 17 from the response graphs A, B and C, such that, the value (or) point closer to the optimized response value of 76.9 degree, is taken so from the graph, it was found that, the dotted line meets at A_1, $B_1$and C_1 coordinate on the X axis.

Hence the optimized response, is given by,

(1) Winding resistance (I-II) = A = A1 = 53.3 Ohms.

(2) Winding resistance (II –III) = B = B1 = 49.8 Ohms.

(4) Main magnet permeability = C = C1 = 460 Gauss.

OPTIMIZATION OF PARAMETERS AND THEIR RESPONSE: (By considering interaction effect of parameters on response – Half position)

Optimization is a continuous process, it can be done further and further as per the optimization is concern, considering interaction effect of parameter on response does provide better optimization than considering only main effect of parameters on response. In connection with the above, the "response table" three more column is added to take into consideration of interaction of AB, AC and AC.

The same observed responses are entered in the modified response table and the estimated main effect and estimated interaction effect are found out for the response of Half position. The modified response table for including the interaction is shown in the table: 13. From the table, the estimated interaction of parameters of AB, AC and BC were as follows,

TABLE: 13 FUEL GAUGE CALIBRATION USING TAGUCHI TECHNIQUE (CONSIDERING THE INTERACTION AMONG THE PARAMETERS)

PRODUCT : FUEL GAUGE

SPEC	MINIMUM	NOMINAL	MAXIMUM
E - H	39 Deg	43 Deg	47 Deg

PARAMETERS	NOTATION
WINDING(I-II)	A
WINDING(II-III)	B
MAGNET	C

RESPONSE TABLE FOR A THREE - FACTOR EXPERIMENT (FOR HALF POSITION)

RANDOM NO	TRIAL	OBSERVED RESPONSE	A		B		C		AB		AC		BC	
			-1	1	-1	1	-1	1	-1	1	-1	1	-1	1
4	1	43.5	43.5	*	43.5	*	43.5	*	*	43.5	*	43.5	*	43.5
1	2	43.5	43.5	*	43.5	*	*	43.5	*	43.5	43.5	*	43.5	*
8	3	45.0	45	*	*	45.0	45.0	*	45	*	*	45	45	*
5	4	44.5	44.5	*	*	44.5	*	44.5	44.5	*	44.5	*	*	44.5
6	5	43.5	*	43.5	43.5	*	43.5	*	43.5	*	43.5	*	*	43.5
3	6	45.0	*	45.0	45.0	*	*	45	45	*	*	45	45	*
2	7	45.5	*	45.5	*	45.5	45.5	*	*	45.5	45.5	*	45.5	*
7	8	46.5	*	46.5	*	46.5	*	46.5	*	46.5	*	46.5	*	46.5
TOTAL		357	176.5	180.5	175.5	181.5	177.5	179.5	178	179	177	180	179	178
NO OF DATA VALUES		8	4	4	4	4	4	4	4	4	4	4	4	4
AVERAGE		44.63	44.125	45.125	43.875	45.375	44.375	44.875	44.50	44.750	44.250	45.0	44.750	44.50
EST. MAIN EFFECT			0.975		1.5		0.5		0.25		0.75		-0.2	

(a) Estimated interaction effect of AB = 0.25^{0}

(b) Estimated interaction effect of AC = 0.75^{0}

(c) Estimated interaction effect of BC = -0.25^{0}

The above values are plotted interms of graphical form is shown in figure: 19 also main effect of parameters are included shown in figure: 18. From the figure: 19 it was found that, "AC" combination having more impact on the response than other combination of AB, BC. Similarly, in the main effect "B" having more impact than A and C.

Based on figure: 19, the "AC" combination can be taken for further optimization, but it is necessary to know, whether there is an interaction among those parameters of "A and C" itself.

Similarly to know, interaction among 'AB, 'BC' a method are followed called "Average response table method" in which an average response are obtained at different combination of those parameters is shown in table : 14, 15 and 16.

Based on the average response tables, the interaction graphs are drawn separately for AB, AC and BC as shown in the figures: 20, 21 and 22 respectively. "By referring the figures it was found that all the combination having a strong interaction between them", is explained by a rule as follows,

(1) When the two lines of graph, "Parallel with each other" represents there is no interaction among those parameters.

(2) When the two lines of the graph "non parallel or interact with each other" represents there is strong interaction among those parameters

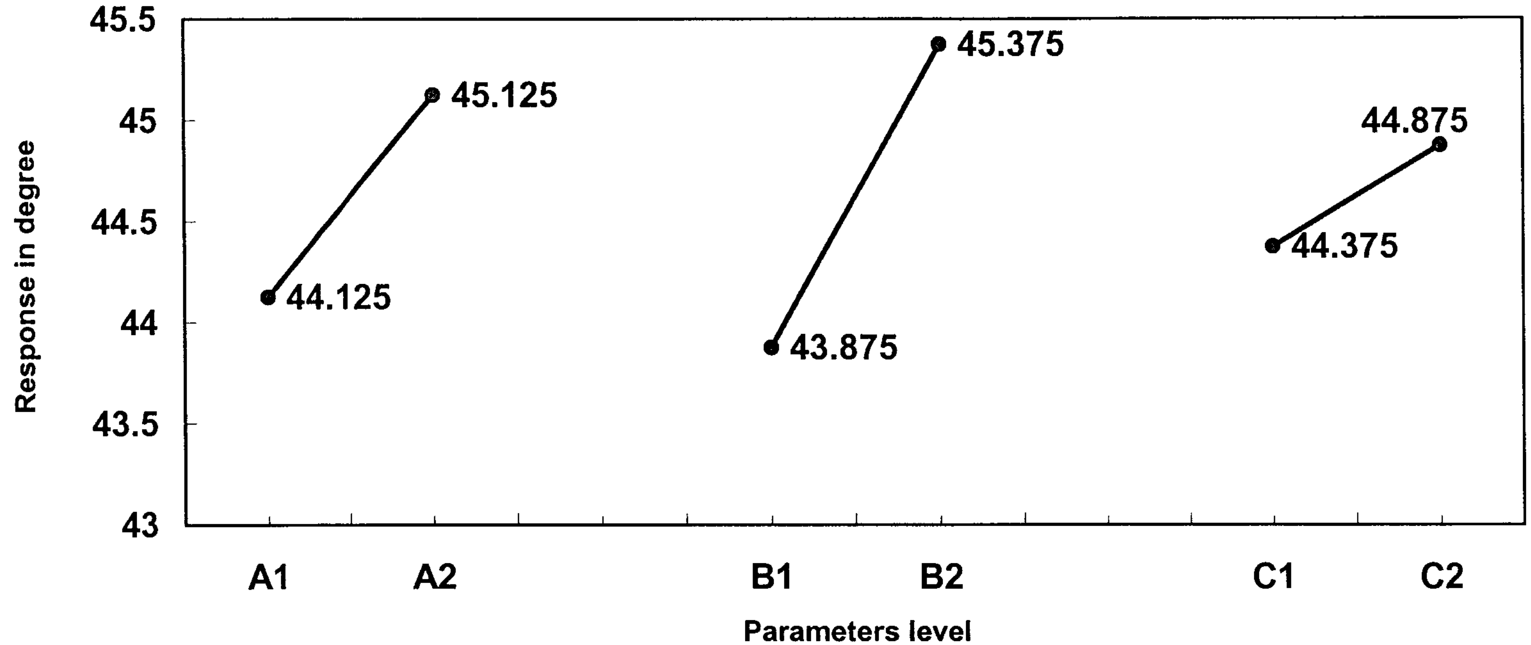


FIGURE: 18 MAIN EFFECT OF PARAMETERS ON RESPONSE
(HALF POSITION)

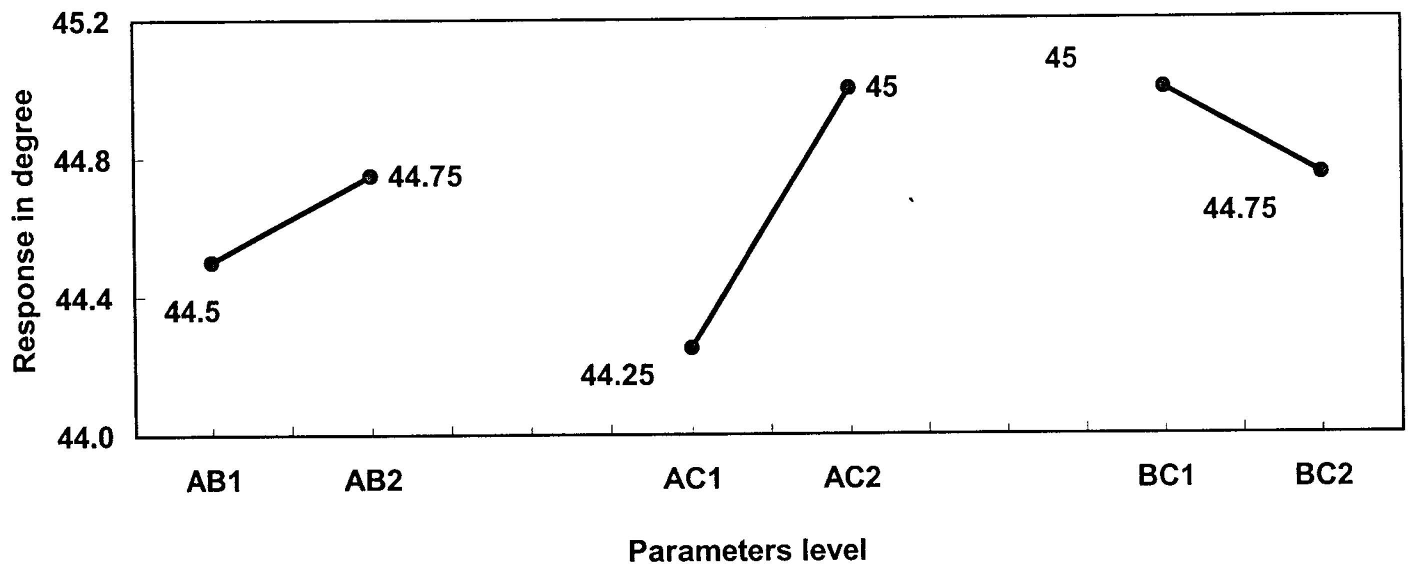


FIGURE: 19 INTERACTION EFFECT OF PARAMETERS ON RESPONSE
(HALF POSITION)

AVERAGE RESPONSE TABLES - INTERACTION EFFECT OF PAF

TABLE : 14 AB INTERACTION

LEVELS FOR FACTORS		OBSERVED RESPONSE	AVERAGE RESPONSE
A	B		
1	1	43.5+45.5	44.5
1	2	43.5+45	44.25
2	1	44.5+43.5	44
2	2	46.5+45	45.75

TABLE: 15 AC INTERACTION

LEVELS FOR FACTORS		OBSERVED RESPONSE	AVERAGE RESPONSE
A	C		
1	1	43.5+45	44.25
1	2	45.5+43.5	44.5
2	1	44.5+43.5	45.5
2	2	43.5+45	44.25

TABLE: 16 BC INTERACTION

LEVELS FOR FACTORS		OBSERVED RESPONSE	AVERAGE RESPONSE
B	C		
1	1	43.5+44.5	44
1	2	45.5+43.5	44.5
2	1	46.5+45	45.75
2	2	45+44.5	44.75

s)

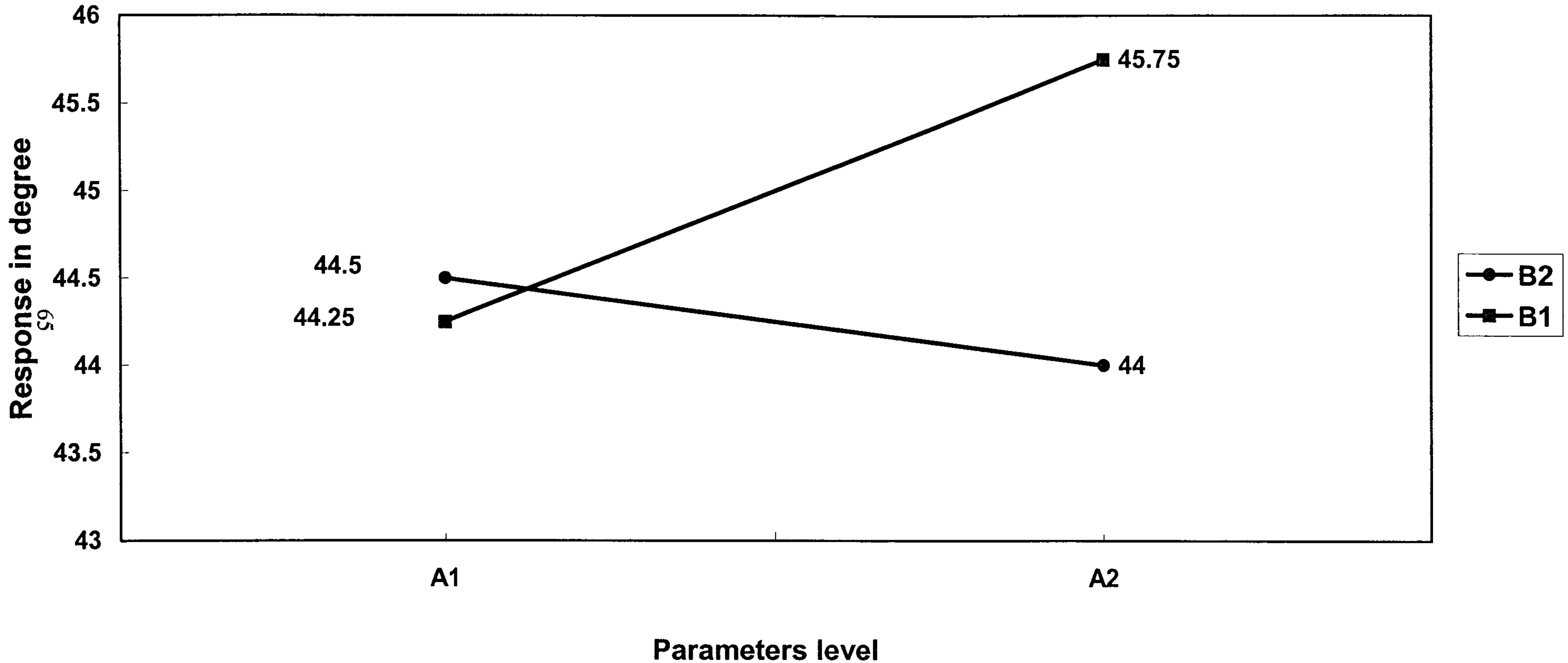


FIGURE: 20 AB - AVERAGE RESPONSE GRAPH

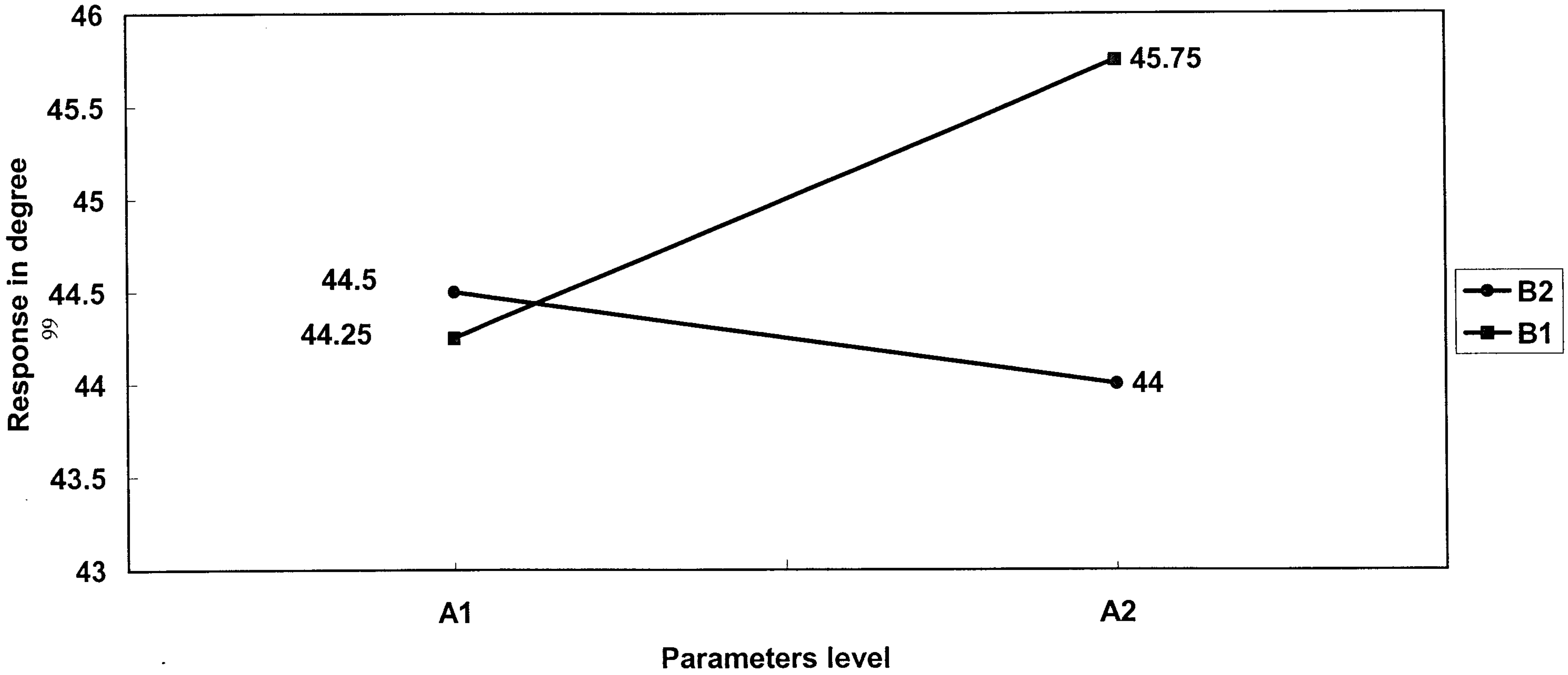


FIGURE: 21 AC - AVERAGE RESPONSE GRAPH

From the above rule (2), the "AC" combination having strong interaction than other, hence it is advisable to select the "A C" combination for optimization, similarly, from the "main effect graph" it was found that "B" having more impact on response. Hence "B" and "AC" are chosen for optimization, is given by the formula.

$Y\ bar_{min}$ = (Grand mean of all responses) + (A and C contribution) + (B Contribution)

= 44.63 + (44.25* – 44.63) + (43.88 – 44.63)

= 43.5 degree

- 44.25 were chosen, from the average response table of AC. I.e., select minimum average response value among all the values. Corresponding levels of A and C are -1 and -1 respectively.

Optimization of parameters:

The parameter level for A and C are selected from the average response table for AC, corresponding to the value of 44.25^{0} as A = 53.3 Ohms and C = 460 Gauss.

The parameter level for B are selected from the response table ( ) as B = 49.8 Ohms.

Optimized response for half position

1. Winding resistance (I-II) = A = 53.3 Ohms.
2. Winding resistance (II-III) = B = 49.8 Ohms.
3. Main magnet permeability = C = 460 Gauss.

TABLE: 17 FUEL GAUGE CALIBRATION USING TAGUCHI TECHNIQUE (CONSIDERING THE INTERACTION AMONG THE PARAMETER!

PRODUCT : FUEL GAUGE

SPEC	MINIMUM	NOMINAL	MAXIMUM
E - H	76.5 Deg	78.5 Deg	80.5 Deg

PARAMETERS	NOTATION
WINDING(I-II)	A
WINDING(II-III)	B
MAGNET	C

RESPONSE TABLE ALONG WITH INTERACTION EFFECT (FULL POSITION)

RANDOM NO	TRIAL NO	OB.RESPONSE (Degree)	A		B		C		INTERACTION OF PARAMETERS					
			1	2	1	2	1	2	A B		A C		B C	
4	1	77.5	77.5	*	77.5	*	77.5	*	*	77.5	*	77.5	*	77.5
1	2	76.5	76.5	*	76.5	*	*	76.5	*	76.5	76.5	*	76.5	*
8	3	76.5	76.5	*	*	76.5	76.5	*	76.5	*	*	76.5	76.5	*
5	4	80	80	*	*	80	*	80	80	*	80	*	*	80
6	5	78.5	*	78.5	78.5	*	78.5	*	78.5	*	78.5	*	*	78.5
3	6	78	*	78	78	*	*	78	78	*	*	78	78	*
2	7	78.5	*	78.5	*	78.5	78.5	*	*	78.5	78.5	*	78.5	*
7	8	79	*	79	*	79	*	79	*	79	*	79	*	79
TOTAL		624.5	310.5	314	310.5	314	311	313.5	313	311.5	313.5	311	309.5	315
NO OF DATA VALUE		8	4	4	4	4	4	4	4	4	4	4	4	4
AVERAGE		78.1	77.63	78.50	77.63	78.50	77.75	78.38	78.25	77.88	78.38	77.75	77.38	78.75
EST.MAIN EFFECT			0.975		1.5		0.5		0.25		-0.63		1.38	

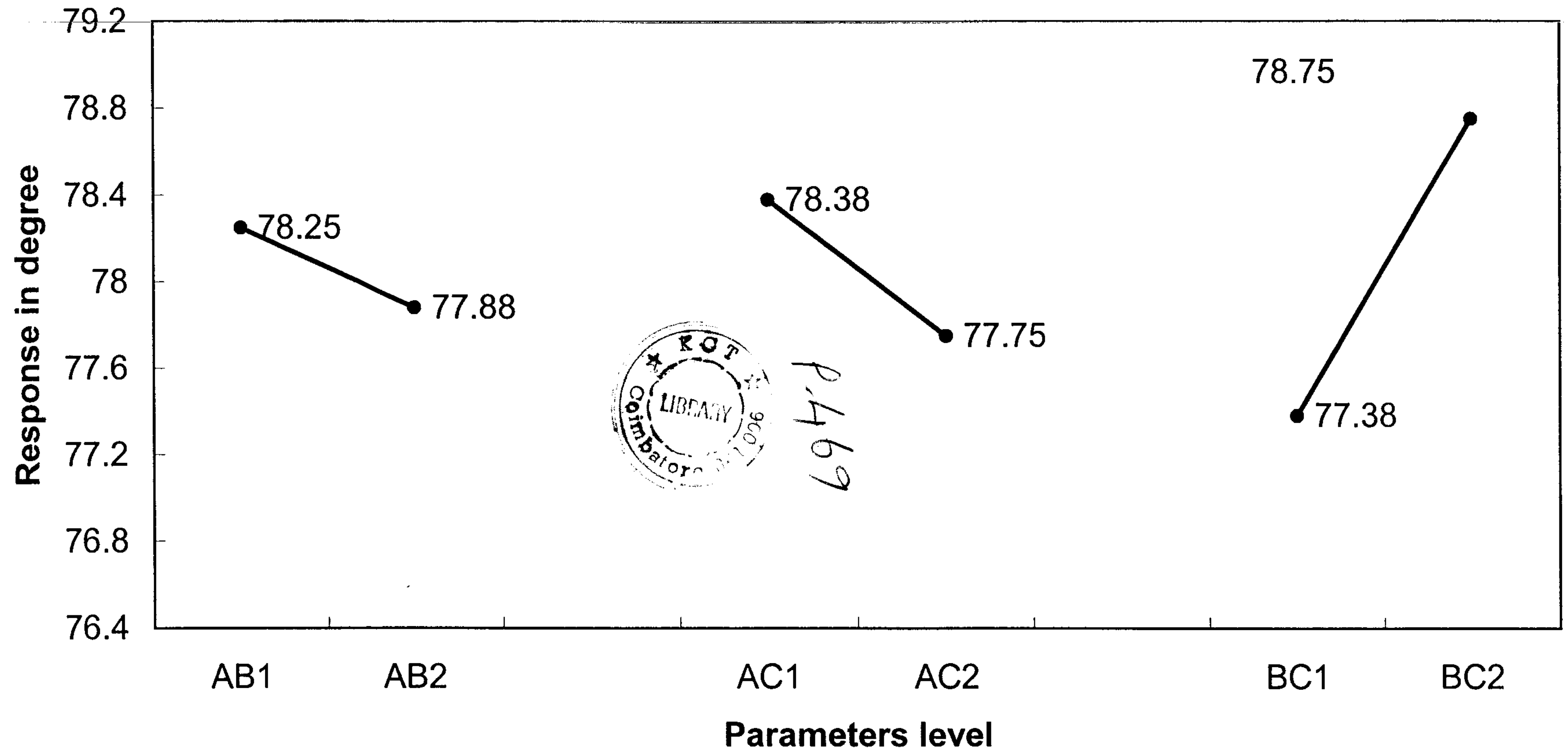


FIGURE: 23 INTERACTION EFFECT OF PARAMETERS ON RESPONSE (FULL POSITION)

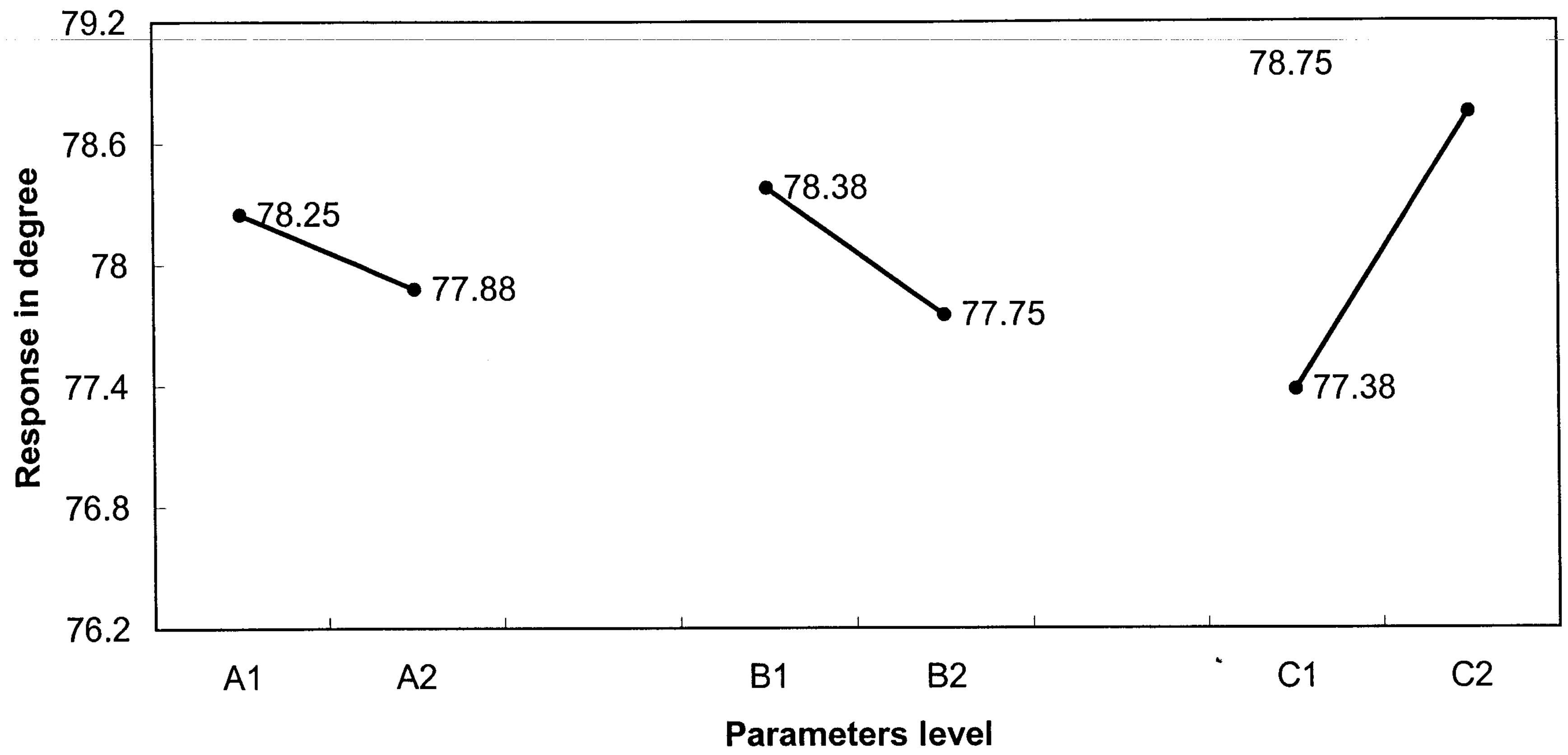


FIGURE: 24 MAIN EFFECT OF PARAMETERS ON RESPONSE (FULL POSITION)

OPTIMIZATION OF PARAMETERS AND THEIR RESPONSE: (By considering interaction effect of parameters on response – Full position)

The same procedure of the above was followed. The observed responses are entered in to the modified response table: 17 and the estimated interaction effects of parameters are obtained for AB, AC, BC.

(a) Estimated interaction effect of AB = -0.375^{0}

(b) Estimated interaction effect of AC = -0.675^{0}

(c) Estimated interaction effect of BC = 1.375^{0}

The above values are plotted interms of graphical form is shown in figure: 23 and combination of main effect and interaction effect is shown in figure: 24. From the figure: 24, it was found that, "BC" combination having more impact on the response than other combination of AB, BC.

Similarly A and B of main effect on response (F) having equal magnitude, but C having less influence on the response (F).

The "BC" combination can be taken for further optimization. As mentioned for response half position, the average response tables are drawn, which is shown in the table: 17, 18 and 19 for AB, AC and BC respectively. But it is necessary to know, whether there is an interaction among those parameters of "B and C" itself. Then based on the average response tables, the interaction graphs are drawn separately for AB, AC and BC as shown in the figure: 25,26 and 27 respectively.

"By referring the figures it was found that all the combination having a strong interaction between them". The BC combination having strong interaction than other, hence it is advisable to select the "B C" combination for optimization. Similarly, from the "main effect graph" it was found that "A" having more impact on response. Hence "A" and "AC" are chosen for optimization, is given by the formula.

AVERAGE RESPONSE TABLES - INTER ACTION EFFECT ON THE RESPONSE(F)

TABLE: 17 AB INTERACTION

LEVELS FOR FACTORS		OBSERVED RESPONSE	AVERAGE RESPONSE
B	C		
1	1	76.5+78.5	77.5
1	2	78+77.5	77.75
2	1	80+78.5	79.25
2	2	79+77	78.0

TABLE: 18 AC INTERACTION

LEVELS FOR FACTORS		OBSERVED RESPONSE	AVERAGE RESPONSE
B	C		
1	1	76.5+78	77.25
1	2	78.5+77.5	78.0
2	1	78.5+79	78.75
2	2	78.5+77	77.75

TABLE: 19 BC INTERACTION

LEVELS FOR FACTORS		OBSERVED RESPONSE	AVERAGE RESPONSE
B	C		
1	1	76.5+80	78.5
1	2	78.5+78.5	78.5
2	1	78+79	78.5
2	2	77.5+77	77.25

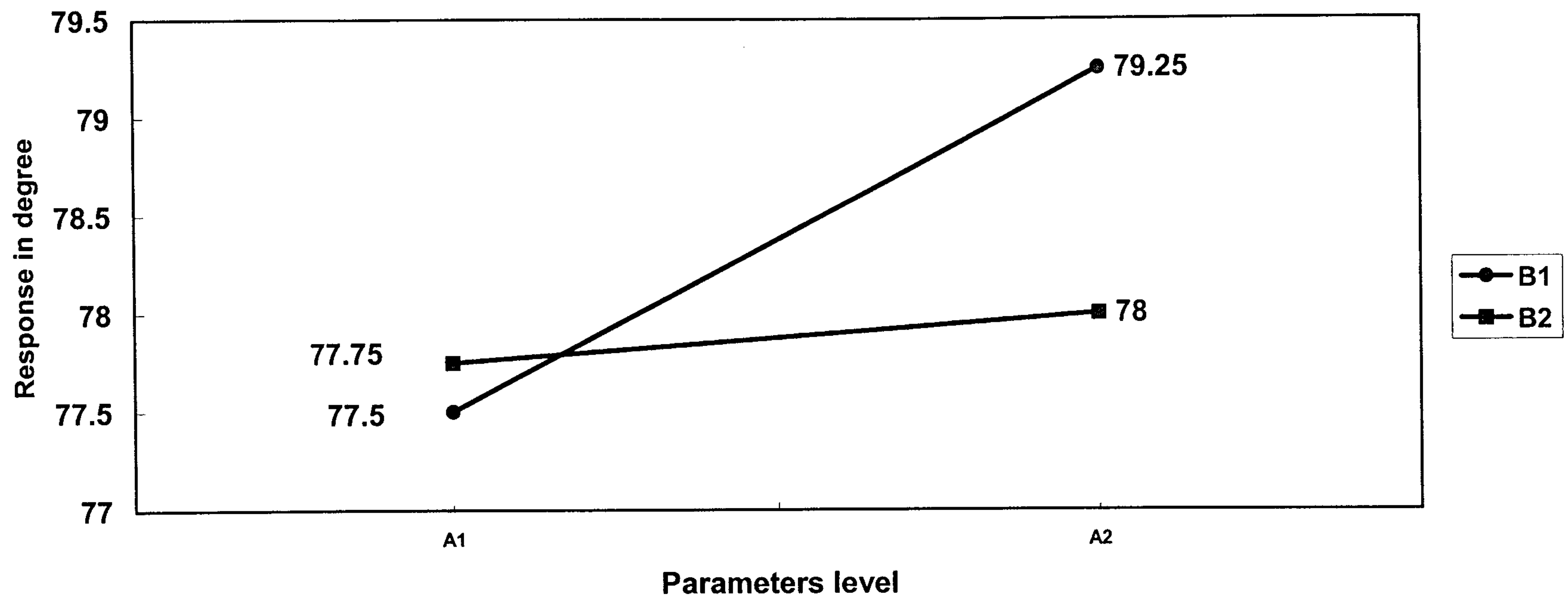


FIGURE: 25 AB - AVERAGE RESPONSE GRAPH

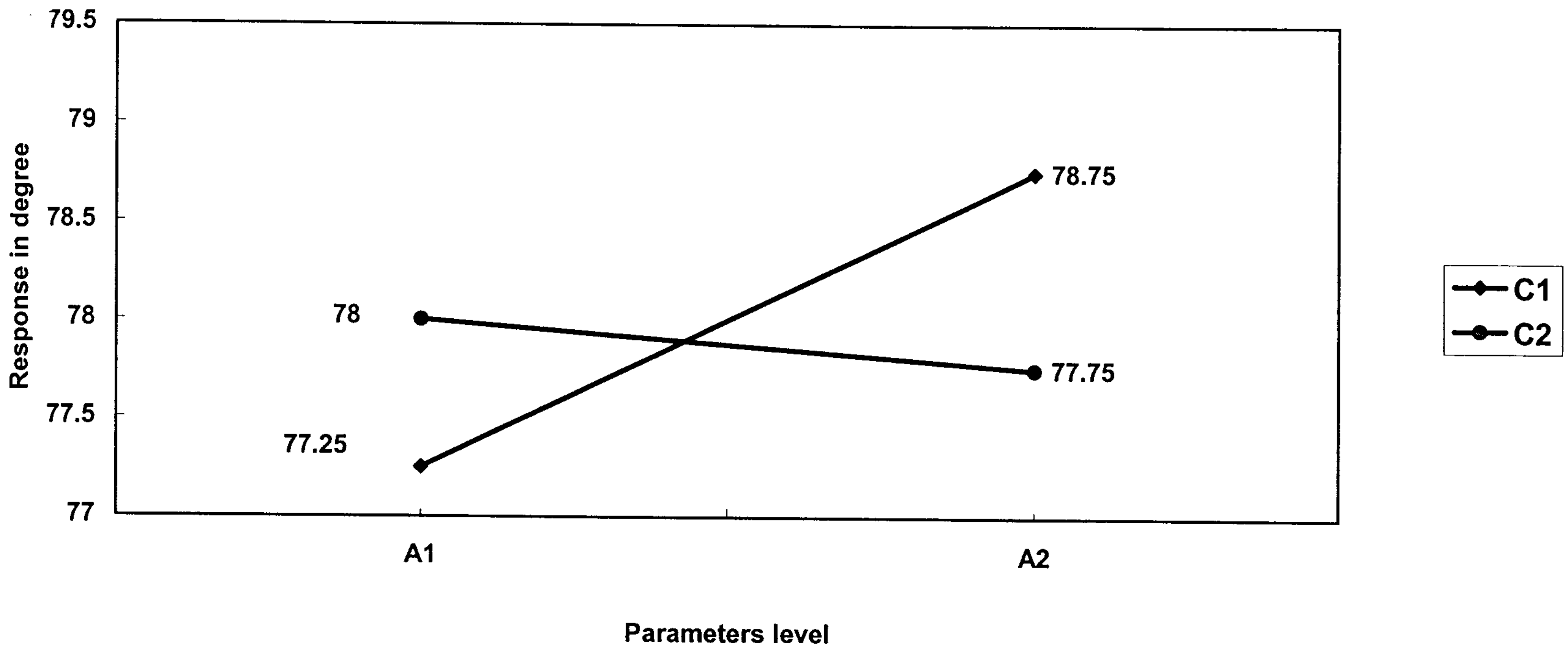


FIGURE: 26 AC - AVERAGE RESPONSE GRAPH

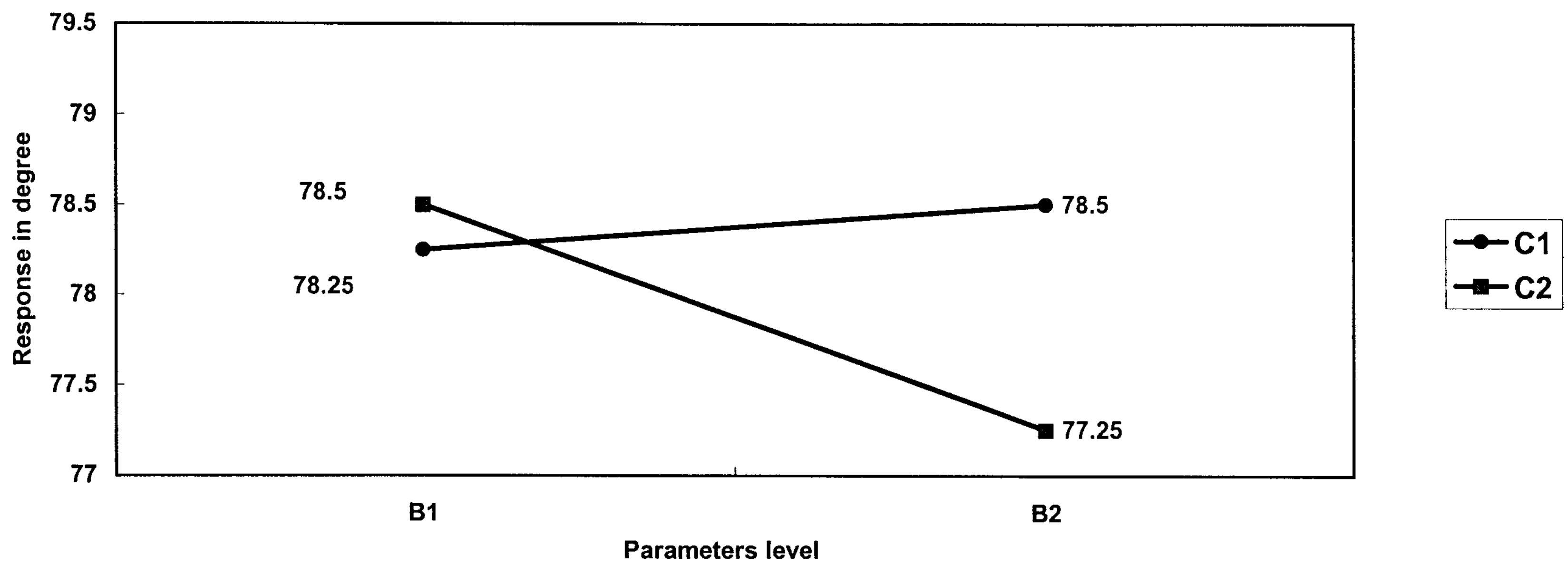


FIGURE: 27 BC - AVERAGE RESPONSE GRAPH

Y bar $_{min}$ = (Grand mean of all responses) + (B and C contribution) + (A Contribution)

= 78.06 + (77.25* – 78.06) + (77.625 – 78.06)

= 76.8 degree

- 77.25 were chosen, from the average response table of BC. I.e., select minimum average response value among all the values. Corresponding levels of B and C are 1 and 1 respectively.

Optimization of parameters:

The parameter level for B and C are selected from the average response table for AC, corresponding to the value of 76.8 ^{0} as B = 50.8 Ohms and C = 505 Gauss. The parameter level for A are selected from the response table: 17 as A = 49.8 Ohms.

Optimized response for full position

1. Winding resistance (I-II) = A = 53.3 Ohms.
2. Winding resistance (II-III) = B = 50.8 Ohms.
3. Main magnet permeability = C = 505 Gauss.

10. Conducting conformation experiment:

Based in the above analysis, the parameters and their responses are optimized. In order to conform the optimized values an experiment was conducted called " conformation experiment"

According to the analysis the optimized parameters and their response are

1. Winding resistance (I-II) = A = 53.3 Ohms.
2. Winding resistance (II-III) = B = 49.8 Ohms.
3. Main magnet permeability = C = 460 Gauss.

Response for half position = 43.5 Degree

Response for full position = 76.8 Degree

The above levels are fixed and the experiments are conducted and the responses were recorded.

Response for half position = 43.5 Degree

Response for full position = 77 Degree.

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

Continuous monitoring and control of any manufacturing results in consistency of product and process.

The case study problem i.e., fuel gauges care affected due to certain parameters in the manufacturing. They have been found by adopting reverse engineering methodology. However, the experts and employees have also conformed the same when it was brought to the knowledge.

It is found that the some of the parameters are not exactly matching with the design specification. A suitable standardization may be thought of with respect to the end application.

1. Main magnet permeability.
2. Main magnet run out.
3. Main magnet face out.
4. Main magnet driving height.
5. Winding turns.
6. Winding resistances.
7. Quantity of oil.
8. Return magnet permeability.
9. Weight of pointer.

For the purpose of optimization three parameters are chosen namely,

1. Main magnet permeability
2. Winding resistance (I-II)
3. Winding resistance(II-II)

The above three parameters which are not exactly matching with the design specification. The optimization of the parameters and the responses are performed by using Taguchi technique, the optimization is carried out by considering main effect and interaction effect of the parameters on the response. And the interaction effect on response provided better optimization than main effect of parameters on the responses.

The optimized parameter and responses are as follows

1. Winding resistance (I-II) = A = 53.3 Ohms.
2. Winding resistance (II-III) = B = 49.8 Ohms.
3. Main magnet permeability = C = 460 Gauss.

Response for half position = 43.5 Degree

Response for full position = 76.8 Degree

Recommendations

1. Above problem can be eliminated by the selection of main magnet permeability value between 460 to 505 gauss value.

2. The winding wires should be with in the specification level of recommendation.

3. Use new technologies to fill the quantity of oil inside the bobbin

4. Provide training to the employees to perform write method of filling the oil.

5. Ultimately selection or purchase materials as per the specification will definitely eliminate error and reduce the percentage of rejection.

CONCLUSION

CONCLUSION

The author's attempt in search of solution to the selected case study problem, fuel gauge calibration have proved that the quality should be improved on continual basis. The experiments conducted resulted in the identification of the parameters and noise factors influencing the quality of fuel gauges. The noise factors may be brought under control if there is an improvement in the process technologies, such as filling exact quantity of oil. etc. It may be that in the earlier decades the importances of fuel gauges were not felt. But, now the scenario has brought every element of a product into focus.

The winding resistance (I-II), Winding resistance (II-III), main magnet permeability are the control parameters influencing the output response in the range setting other than the noise factor (i.e.) quantity of oil. The output response has been optimized with the help of Taguchi's design of experiments. They are recorded as follows

The optimized parameter and responses are

1. Winding resistance (I-II)	= A = 53.3 Ohms.
2. Winding resistance (II-III)	= B = 49.8 Ohms.
3. Main magnet permeability	= C = 460 Gauss.
Response for half position	= 43.5 Degree
Response for full position	= 76.8 Degree

The conformation experiments show that there is an improvement in the reduction of percentage of rejection. Hence, the rejection percentage could be brought it down to a large extent provided we implement the recommendation in the system. However, the author and the guide feel that there are lot of scope for further improvement.

Scope for research:

The extension of the above research can made much more better by selecting more than two levels. In connection with this, three levels are chosen in order to perform analysis by using another optimization tool is called "Central Composite Rotatable Design". Based on that, the number of experiments to be conducted is increased and experiments are conducted by taking into consideration of three levels for each parameter. The analysis work is under the progress, it will completed in future.

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