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MATHEMATICAL MODELLING AND SIMULATION OF WORKING OF AN ENTERPRISE MANUFACTURING ELECTRIC MOTORS

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Assembly of electric motor is a complex phenomenon. The phenomenon includes the worker who assembles the motor and his working environment such as the table on which he is working and chair on which he is sitting during the assembly. In addition to this, various parameters such as design of tools involved in assembly of electric motor, amount of energy worker puts in during the assembly, anthropometric data of the workers, working conditions such as humidity, temperature etc. also influence the productivity of assembly operation. Considering these parameters the two important aspects to be considered are productivity of electric motor along with the comforts to the workers. The aim of the work was to increase the productivity of electric motor assembly keeping in mind more convenience to the workers. Out of so many parameters mentioned above we would like to find out which of these parameters are most important for increasing the productivity and also reducing the human energy input. Simultaneously it would be interesting to know influence of one parameter over the other.

Keywords: Stator, Rotor, Motor, Human Energy Input, Models, Ann Analysis, Regression Analysis, Optimization, Nomograms, Productivity

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1. STATE OF ART OF ASSEMBLY PROCESS

Assembly is the technical term used commonly in manufacturing industries for putting parts together in the final stages of a production line. The technology of assembly has been assuming increasingly important role in manufacturing industries, prompted by constant drives for higher efficiency and productivity. Even though some processes in assembly lines have been automated to varying degree, manual assembly is still indispensable in processes where a high degree of manual manipulation is required. In Indian context and in the context of other countries of the third world where manpower is available in abundance manual assembly takes front seat as compared to automated assembly or robotic assembly.

Literature review carried out shows that research on assembly task has proceeded mainly along three directions

1) Motion and time studies (Chung 1983, Maynard 1948)
2) Generation of assembly sequences (De Fazio and Whitney 1987, Homen de Mellow & Sanderson 1989 & Lei 1988)
3) Cognitive Models of assembly tasks (Baggett & Ehrenfeucht 1988; Baggett & Ehrenfeucht 1991, Fish 1993, Van Santen 1970, wild 1970)

None of the research till date has measured effect of parameters such as good workplace, better working conditions, proper design of tools, tool arranged in proper sequence, anthropometricaly designed chair and table on the productivity and occupational health implications of these parameters.

Awkward working posture can lead to discomfort or injury. Working posture is determined by interaction of many factors in the work place such as workstation layout, visual demands, hand tool design, anthropometric characteristics of the workers and work methods. Low or extended reaches may involve significant trunk flexion while lateral reaches may involve axial twisting. High or far reaches may involve significant elevation of the shoulder. Little research has been done relating occupational health risks of the operators to the layout of the assembly.

One factor of importance in determining the operators posture and use of hands is the design of the work place and specially the layout of the parts and location of work within the workplace.

1.1 Selection Of An Industry

Nagpur Motors, M.I.D.C., Nagpur (India) is a Small Scale Industry involved in assembly of electric motor was selected for carrying out the experimentation. This industry is engaged in assembly of motors of different types. But as the production of 1 HP motor is highest in this industry, assembly of 1HP motor was targeted.

1.2 Approach To Realize The Objective

The objective of the present work was to increase the production and to provide more convenience to the workers. The approach decided to tackle this situation is as mentioned below

- Video filming of the entire process particularly stator assembly work station and motor assembly work station
- Critical study of video film
- To carry out the method study of present method of assembly.
- To measure the anthropometric features of the workers
- To do the time study of the present method
- While doing time study to measure the heart rate of the workers doing assembly
- To measure the human energy input of workers doing assembly
- Find out the possibility of measuring the human energy input without using bicycle ergo meter.
- Find the best method of carrying out the assembly and design the workstation
- Again do the method study, particularly charting of two handed process charts so as to know improvement of the method.
- To do the time study of the improved method
- To measure human energy input of the workers with improved method
- Compare both the methods i.e. present method of assembly and improved method of assembly and to find out saving in human energy input.
- Measure the parameters affecting assembly phenomenon for present method
- Measure the parameters affecting assembly phenomenon for improved method
- Formulate the model for present method of assembly using Theory of Engineering Experimentation[54].
- Formulate the model for improved method of assembly again by theory of engineering experimentation.
- Carry out regression analysis of the experimental data.
- To perform ANN simulation of experimental data.
- To optimize the models obtained
- To carry out the sensitivity analysis
- To plot the Nomograms for getting graphical relationships
- Compare the models

1.3 Present Method Of Assembly

One H.P. Motor has in all 16 parts that are to be assembled, which are as follows:
Motor body ,Stamping stack, Winding coils (6 Nos.) ,Plastic paper strips (48 Nos.), Rotor shaft , Aluminium rotor, Front and rear end shields , Bearings (2 Nos.), Fan ,Fan cover, Studs with nuts (3 Nos.) , Terminal plate, Lugs (3 Nos.) , Key, Split pin , Insulation paper. The assembly process can be divided into three main sub groups i) Stator assembly ii) Rotor assembly and iii) Motor assembly. This complete assembly process was video filmed so as to get minute details of the process.

Stator Assembly Process

The Stator assembly process is represented by a block diagram in Fig. 1. Winding coils are normally hand wound and after subjecting them to resistance test before they are stored in the stores. Similarly the stamping stacks are also stored in stores. The winder receives the stamping stack and required coils from the stores. Winder inspects the stamping stack for burs & other damages. It he finds any, he does filing and removes the burs. Winder then cuts the insulating paper strips of required length from the sheets. After cutting the sheets he inserts the paper strips into the slots, making sure that the paper is folded at both the ends. The coils issued from the stores are then inserted into the stamping slots. 1 HP motor requires 6 coils, one coil is inserted in 4 slots. The insertion of the coil is done by both the hands and a wooden stick is used for insertion of coil. The inserted coils are again covered by plastic paper. Overhung coils are then tied with a thread and finally connections are made. This wound stator is subjected to a) high voltage test, b)surge comparison test and c) terminal resistance test. If found defective it is reworked and again tested till it is OK or rejected.

The wound stator is then sent for varnishing. Wound stators are varnished in a batch size of 20-25. In case or emergency a small size is also varnished. These stators are then heated in an oven for about 2-3 hours for dehumidification. After complete removal of moisture, varnish is poured on both sides of the overhung coils. These stators are then placed horizontally in the oven tray and heated for 6-8 hours for baking. The oven automatically switches off after preset time and wound stators are allowed to cool in the oven itself. The baking process normally starts at the end of the day so that the stators are ready for assembly next day morning. An anticorrosive chemical Becktol is applied on the exposed overhung windings. These stators are then stored in stores so that they can be issued to motor assembly workstation. Various tools that are engaged in assembly of stator are Mallet, Pliers, Cutter, Wedges, Scissors, Paper Cutter & Blade.

Rotor Assembly Process

The company purchases the raw material i.e. shaft and aluminium pre-diecast rotors from the market. The shafts are cut into required length in a machine shop by a hack saw. The shafts are turned and machined in the shop as per the drawings in the machine shop. The machined shafts are pressed into aluminium pre-diecast rotors using hydraulic press. These aluminium pre-diecast rotors are outsourced by the company. Pressed rotor shafts are then machined to size and complete rotor is made. This rotor is then stored in stores so that it can be issued to motor assembly workstation.

Motor Assembly Process

Motor assembly process is represented by a block diagram shown in Fig. 2. At this workstation Varnished stator, is pressed in a motor body using hydraulic press. Completely machined ready to use motor body is received by the company as a bought out item and is stored in store till it is issued for motor assembly. The bearings are then pressed manually on the rotor shaft using pressing tool. The rotor is inserted in the stator and end shields are fixed using studs. The terminal plate is fixed in the terminal box. Extra wires if any are cut and lugs are fixed to the wires. The lugs are then fixed to terminal plate studs. The fan is fixed and locked with split pin. The fan cover is fixed with the screws. The key is placed in the keyway and is taped. This completes the assembly of motor. The motor is then subjected to following tests. (a) High Voltage, (b) No Load, (c) Locked rotor at reduced voltage.

The motor is painted in the paint shop and is stored. The painted motor is then stored in the stores. Tools are used for motor assembly are Mallet, Hammer, Cutter, Pliers, Spanners, Screw Drivers, Blades, Crimping tool

1.4 Design Of Experimentation

Approach

A theoretical approach can be used if known logic can be applied correlating various dependent and independent parameters of the system. Based on the available literature the relationship between dependent and independent parameters is qualitatively known but generalized quantitative relationships are not known many times. Whatever quantitative relationship is known for Anthropometric data, it is not available for Indian workers working in particular industry. Thus it is difficult to formulate quantitative relationship based on known logic. Since it is not possible to formulate theoretical model, only possibility is to create a field data based model. Thus formulation of field data based model is aimed at in the present work.

The approach suggested by Hilbert (1961)[54] to formulate generalized experimental model is considered as follows:

Identification of Parameters/variables

Any physical quantity that undergoes a change can be said to be a variable in general sense. If particular variable can be changed without affecting other variables / parameters then it is independent variable/parameter. Similarly if a particular variable changes in response to variation of one or more parameters it is called as dependent or response parameter/ variable. If the physical quantity changes in random or uncontrolled manner then it is termed as extraneous variable.

Various parameters or variables affecting the phenomenon of assembly are worker, work station and the environment where assembly is being done. These variables are all the time interacting with each other.

Dependent variables identified in case of assembly of electric motor are :

1. Productivity i.e. partial cost of assembly with respect to time
2. Human energy input

There are many independent variables that are difficult to list and hence they have been grouped as under.

- Anthropometric features of Indian workers
- Dimensions of table and chair where assembly of motor is done
- Environmental factor
- Geometry of the tools used
- Continuous assembly time

Cost of Partial Assembly

1 HP motor has many parts, which are being assembled one after the other. The cost of individual components is gathered from the purchase department. As the cost of individual components is known, cost of partial assembly at a particular instant of time "t" can be calculated.

Human Energy Input

Human energy input can be measured in different ways. Heart rate measurement is the simplest method of estimating human energy (Kroemer et.al. 1994) [53]

Anthropometric Data of Indian Workers

Work station where assembly is done has to be designed such that it offers maximum comfort to the workers. Dimensions of chair and table plays very important role for providing comfort to worker and they are decided on the basis of anthropometric data of Indian workers. Various Anthropometric features such as Buttock knee depth (a), Buttock poplitial height (b), poplitial height (c), Elbow to Elbow breadth (d), Hip breadth (e), Functional forward reach (f), Thigh clearance (g), seating elbow height (h), seating eye height (j), seating height (k) are considered as important variables. They are shown in Fig. 3.

Geometric Features of Table and Chair

Geometric features of chair and table should be designed to give maximum comfort and to avoid occupational awkward postures [Murrel (1986)[31], ANSI(1988)[56], Oborne(1986)[57], Diffrient et. al. (1974)[58]]. Geometric features such as height of chair 'H', depth of chair 'L', width of chair 'W' along with height of table 'Ht', length of table 'Lt' and width of table 'Wt' are considered as independent variables.

Environmental Factor

Apart from above mentioned factors, various environmental factors such as air temp 'Dt', relative humidity 'ϕ' and air speed 'v' in m./min, Heat in joules are taken as independent parameters.

Tool Geometry

Tools used for assembly of electric motor are mallet, pliers, cutter, wedges, scissors, paper cutter blade, O.D. checking ring, spanners, screw drivers, hammer. Dimensions of these tools are taken as independent variables. Tool used along with their dimensions are shown in Fig. 4

Continuous Assembly Time

Duration of continuous assembly time 't' for stator as well as motor is considered as independent variable, which is done on table of length 'Lt'.

1.5 Dimensional Analysis

As the number of independent variables is too large, they are reduced to few using dimensional analysis. It is done by applying Buckingham's theorem (Hilbert 1961)[54]. When this theorem is applied to a system having "n" independent variables, (n-4) number of pi terms is formed. Four primary dimensions used are L, M, T, θ. When independent variables are large even after applying this theorem number of pi terms will not be reduced than n. If the product of these pi terms is taken then it will yield dimensionless pi term. This approach is used to reduce the number of variables and following pi terms are formed logically.

Pi term Relating to Anthropometric Data

$$\pi 1 = \frac{axbxcxdxe}{f\,xgxhxj\,xk} \qquad \ldots \qquad (1)$$

Where a, b, c, d, e, f, g, h, j, k are the anthropometric dimensions as shown in Fig. 5.1. i.e. (a)Buttock knee depth , (b)Buttock poplitial height, (c) poplitial height, (d) Elbow to Elbow breadth, (e) Hip breadth, (f) Functional forward reach, (g) Thigh clearance, (h) seating elbow height , (j) seating eye height , (k) seating height.

Pi term Related to Dimensions of Chair and Table

$$\pi 2 = \frac{HxLxW}{HtxLtxWt} \quad \ldots \quad (2)$$

This pi term is used for stator assembly wherein both table and chair are used during the assembly. Motor assembly is done in standing posture and hence pi term is slightly modified as π2 = (Ht x Lt) / Lt x Lt) Where H,L,W are height, length and Width of the chair respectively and Ht, Lt and Wt are the height, length and width of the table.

Pi term Related to Humidity

Relative humidity is measured in % and hence it is taken as one of the pi terms

$$\pi 3 = \phi \quad \ldots \quad (3)$$

Pi term Related to Geometry of Tool

Dimensions of various tools used for assembly of motor and stator are measured. Logically dimensionless numbers for each tool is prepared and finally product of these individual numbers is taken to form a pi term. Tools used are shown in Fig. 4.

$$\pi 4 = M \times N \times C \times S \times B \quad \ldots \quad (4)$$

Where M is pi term denoting dimensions of Mallet, N represents dimensions of Nose pliers, C dimensions of cutter, S dimensions of scissor, and B dimensions of Blade.

Pi term Related to Continuous Assembly Time

Continuous assembly time is measured and pi term is logically formed as under

$$\pi 5 = \frac{gxt^2}{Lt} \quad \ldots \quad (5)$$

where g is the acceleration due to gravity and 'Lt' is the length of table.

Pi terms Related to Dependent Variables

There are two dependent variables and hence two dependent pi terms. They are π6 a pi term related to human energy input and π7 which refers to pi term related to partial cost of assembly.

To find the dimensional equations for pi term involving the dependent variable HE (Human Energy) Buckingham's pi theorem is applied.

$$\pi 7 = (V)^i x(Dt)^j x(Heat)^k x(Wi)^m x(HE) \quad \ldots \quad (6)$$

$$L^0 M^0 T^0 = \left(\frac{L}{T}\right)^i x(\theta)^j x\left(\frac{MxL^2}{T^2}\right)^k x\left(\frac{ML}{T^2}\right)^m x\left(\frac{ML^2}{T^2}\right) \quad \ldots \quad (7)$$

Equating indices of left hand side and right hand side

For L

0 = i+2k+m+2

i=-2k-m-2

For M

0 =k+m+1

k=-m-1

For T

0 = -i -2k –2m-2

i = -2k-2m-2

For θ

j = 0

Substituting the values

i = 2m+2-m-2, i = m

Substituting values of m
m = 2m + 2 - 2m - 2
m = 0
substituting value of i=0, j=0, k=-1 and m =0

$$\pi 6 = \frac{HE}{Heat} \quad \text{...} \quad (8)$$

Pi term Related to Partial Cost of Assembly.

The cost of individual items being assembled at a particular instant of time is taken into consideration. The wages of the workers per day are also known from the accounts department and thus pi term relating to partial cost of assembly can be logically formed as under

$$\pi 7 = \frac{Cp}{Cw} \quad \text{...} \quad (9)$$

Where Cp is the partial cost of assembly at a particular instant of time and Cw is the wages of the worker doing the assembly per day. The equations for various dependent and independent pi terms are summarized in Table 1.

1.6 Determining The Ranges Of Pi Terms

There are numerous individual variables contributing to this complex phenomenon of assembly. It is therefore necessary to determine the ranges of all these variables. It is not possible to determine ranges of all the variables and hence the range of pi terms involved is determined.

a) Range of $\pi 1$

The anthropometric data of all the workers is obtained . The values of a, b, c, d, e, f, g, h, j and k are measured and are substituted in the equation No. 1 of $\pi 1$. By arranging the data in ascending or descending order, the maximum and minimum values of $\pi 1$ are obtained.

Helper working with skilled labour:

Whenever in any operation more than two workers are working in order to accomplish one task interaction takes place of the inputs provided by two workers in every way to accomplish the process. As a result of these two inputs interacting with the task, that the task is accomplished. Here the question is of how to simulate anthropometric data of two workers accomplishing the assembly task? One possible way to simulate this situation is to look upon two workers as if they are two independent energy sources. The task to be accomplished, as if it is a load to be shared by two energy sources. If the situation to be thought to be analogous to that of machine with two degree of freedom having two independent energy paths, feeding power to one sink i.e. a load. It is well known in the case of machine that the overall effectiveness of energy transfer is by the product of the efficiencies of the two machines. Similarly here the actual anthropometric data would be the product of anthropometric data of two workers. Hence in the observation table of all the workers, for some observations the value of anthropometric data is obtained by multiplying the anthropometric data of two workers. Here one worker is a main worker whereas other is a helper.

b) Range of $\pi 2$

This is a pi term related to dimension of chair and table. The range is constant for present method of assembly as well for the improved methods of assembly.

c) Range of $\pi 3$

This is the pi term related to environmental factors particularly to humidity. Its effect is also considered for assembly of electric motor. The range has been obtained from the meteorological department.

d) Range of $\pi 4$

Various tools are used for the assembly of electric motor. Tools used for stator assembly as well as motor assembly were considered to be the influencing factors. Their dimensions were logically set to get the pi terms. The values relating to geometry of the tools remains almost constant, as tools have fixed dimensions.

e) Range of $\pi 5$

As the time of continuous assembly changes, this pi term also changes. The range of this pi term can be obtained by arranging the pi terms in ascending or descending order. This pi term changes at every instant of time as the assembly operation proceeds.

1.7 Determination Of Test Points

The most obvious way to start test point selection is to decide on the end points or limits which will give test envelope that encloses the complete family of data.

There are two major criteria governing test point selection

1. Relative accuracy of data in different regions of test envelope
2. Nature of experimental function

In the present case as the nature of experimental function is not known prior to test this criteria can not be used. Sufficient number of readings are taken to satisfy the first criteria.

The spacing of the test points is not adjusted just to get a symmetrical or pleasing curve, but to make sure that every part of experimental curve or map has the same precision on all parts. It is difficult to achieve this ideal condition because of so many limitations viz. 1) As the experimentation is done in an industry it is difficult to have laboratory type of set up there 2) It is not physical phenomenon like increase in temperature of lubricant or wear of bearing in journal and thus regular procedure of deciding the test points, test envelope and experimental planning is not within control 3) The workers doing the assembly job keep on changing. Due to this the pi term related to anthropometric data also changes. Thus instead of proper spacing permissible spacing of test points is considered.

1.8 Sequence Of Experimental Testing

After deciding the spacing of test points the sequence of experimental testing has to be decided. In engineering two types of experiments are considered 1) Irreversible : This is a test that proceeds irrevocably from past to future without chance of alteration 2) Reversible. It can be said that all tests are basically irreversible, in the sense that no system ever returns to an identical configuration after use. In reversible tests changes made by testing are so small that they can not be detected. There are two plans 1) Sequential plan where the test starts at extreme upper or lower value and changes in steps till other extreme is reached. 2) Random plan, where the test starts and variables are varied in randomized fashion. In present test as in majority of engineering experiments random sequence is selected.

2. DETERMINATION OF PLAN OF EXPERIMENTATION

Many discrete extraneous variables like group of men, different machines and instruments, different days of week or seasons of the year can be taken care of by concept of randomized blocks like Latin squares, or Graeco-Latin squares, which are among the general family of factorial plans (Logothesisi, 1977). For multifactor experiments two types of plans viz. classical plan or full factorial and factorial plan are available In this experimentation conventional plan of experimentation is recommended. There are two work stations i.e. Stator assembly and Motor assembly work stations. There are four workers working at stator assembly workstation whereas there are two workers assembling the motor at motor assembly work station. Two workers act as helpers to either stator or motor assembly work. The experimentation can be planned to be spread over one complete year so that all the seasons of the year can be taken care of.

2.1 Instrumentation

The heart rate of worker was measured manually by using the digital clock. It was measured throughout by only one person so as to minimize the error of measurement. For doing the time study split type stop watch was used. For measuring the air speed in m/s or dry bulb temperature in 0^0C Anemothermometer was used. It has digital display. The measurement of air speed or dry bulb temperature can be obtained by switching corresponding buttons. Humidity was measured by 'Bargo' make meter. It can display relative humidity along the dry bulb temperature. To measure the anthropometric data instruments used were scale, trisquare, protractor etc.

3. PROCEDURE ADOPTED TO CONDUCT EXPERIMENTATION AND EXPERIMENTAL RESULTS

3.1 Evaluation Of Present Method

After viewing the video of complete motor and stator assembly it was decided to carry out method study, time study, human energy input, anthropometric data collection for the present method. After doing these studies it was decided to find the possibility of redesign of the workstation and again carry out all the studies on the improved workstation to confirm the improvements in the new workstation.

3.2 Method Study

Present method of assembly was video filmed to get the minute details of the process. Work in the factory is assigned in the morning. It was explained to the workers that what is being observed and the objective of the study i.e. the productivity of the industry is being evaluated and how it can be improved so that it is beneficial to management as well as to the workers in the sense that the workers will operate at minimum energy input resulting in the comfortable environment. The work started at 9.30 a.m. Flow process chart was prepared for the complete assembly process along with the distances associated with functions. All the activities done by the left hand and right hand were noted on the sheet. The hands were charted one hand at a time and a two handed process chart was prepared for present method of assembly of stator,. Similarly two handed process chart was prepared for Present Method of Assembly of Motor. The observations of two handed process chart for both stator and motor assembly are summarized in the Table 2.

This shows that for stator assembly the use of right hand is more for doing operations also it is clear that left hand is less used for operations during motor assembly. From Table 2 it is clear that there is disparity in motions of left hand and right hand. This means there is scope for improvement in the method of assembly process by proper sequencing and arranging the tools, also redesigning the work station has to be thought of.

3.3 Time Study

The company is manufacturing motors of 1 HP. The assembly process was divided into small elements. For time study, initially observational readings were taken as shown in Table 3. These observational readings were used to determine the sample size of number of readings to be taken for time study. Time of each activity was recorded using stop watch. As confidence level of 95 percent and ± 5 percent precision is normally expected following formula [29] was used to get sample size.

$$N = \left(\frac{40\sqrt{N^1 \Sigma X^2 - (\Sigma X)^2}}{\Sigma X} \right)^2 \quad \ldots \quad (10)$$

where N = sample size

N^1 = Number of preliminary readings

Σ = Sum of values

X = Values of the readings

The sample size resulted into $N^1 = 3$ and hence 3 readings of timing were taken and are shown in Table 3. Based on these readings Basic Time and Standard Time was calculated. Since the average experience of the workers was 2 years they were rated at 85 on a scale of 1-100 [29]. Based on this rating basic time was calculated.

$$\text{Basic Time} = \frac{\text{Observed time x Observed rating}}{\text{Standard rating}} \quad \ldots \quad (11)$$

Fatigue allowance of 4% of basic time was considered in calculation of allowances[29]. Considering various stresses & strains during the work, points were allocated. The total points calculated were 11. Variable allowance of 11% was taken from the Point conversion table for these 11 points [29]. Total allowance = 4% of Basic time + 11% of Basic Time was calculated [29].

Standard Time = Basic Time + Total Allowances ... (12)

Productivity based on standard time was calculated. Assuming working of the factory for 25 days, productivity works out to be 25 x6 =150 motors in a month. The actual production of the company from the record of the company is 104 motors per month.

3.4 Work Table And Sitting Arrangements

Dimensions of work table and sitting arrangement were taken to find out the ease with which workers are assembling the motors. The table on which stator assembly is made has dimensions of 77 cm length x 108 cm breadth x 90 cm height whereas the sitting stool has dimensions of 36 cm length x 38 cm breadth x 64 cm height .The table on which motor assembly is done has dimensions of 121 cm length x 119 cm breadth x 92 cm height. Normally motor assembly is done in standing posture, hence dimensions of sitting arrangement are not included. There are four workers engaged in stator winding shop, two workers in motor assembly and two helpers to assist workers of motor and stator assembly, their anthropometric data was collected as shown in Table 4. The data collected can be used to decide the dimensions of new work station.

3.5 Human Energy Input

During time study, simultaneously pulse rate of the worker was measured. This was done for complete operation of assembly of stator winding. The sample observations are presented in Fig.5. Similarly this was done for complete motor assembly process,

The area under these curves comes out to be 4460.42 pulses for stator assembly process (Fig. 6) and 1250.92 pulses for motor assembly process(Fig.7). These areas under the curves represent human energy input for respective operations. This human energy input needs to be stated in Engineering units of N-M., for this purpose normally bicycle ergometer should be adopted. However, in view of the actual work as it is carried out in the industry and because of some reservations on the part of workers an alternative method, in fact two methods as described below were thought of.

Method 1: An ergonomist may not agree to this method as an alternative to a bicycle ergometer. However in view of the reasons stated earlier of not using bicycle ergometer for this purpose in an ergonomic laboratory, a method fairly close to the same is thought of and executed.

A bicycle was arranged with a certain weiht on its carrier. The same worker was asked to ride the bicycle over a certain distance. The pulse rate was recorded at the beginning of ride & at the end. The variation in pulse rate as observed during this test is presented in Fig 8. The area under the curve comes out to be 179.4 pulses for worker 1 and 202.1 for worker 2.

During this ride, the work done in N-M in riding the bicycle can be estimated as under. Various forces acting during bicycle ride are shown in Fig 9.

Let R_R – Rear wheel reaction
R_F = Front wheel reaction
L= Distance traveled by the rider
D= Diameter of bicycle wheel
Total moment of resisting force = $(\mu R_R \times D/2) + (\mu R_F \times D/2)\ \mu$
No. of revaluations $N = L/\pi D$
W1= Weight placed on the carrier
W2= Weight of the worker
W3= Weight of the Bicycle

Total work done $= 2\pi N\ [R_R + R_F) \times \mu \times D/2$

$R_R + R_F$ = Weight on carrier +Weight of man + Weight of bicycle
= W1+ W2+ W3

Total work done $= 2\pi N\ (\mu R_R\ D/2) + 2\pi N\ (\mu R_F\ D/2)$
$= 2\pi N\ D/2\ \mu(R_R+R_F)$
$= 2\pi\ L/\pi D\ \mu \times D/2\ (R_R+R_F)$
$=$ (Total Weight) x L x μ

The observations and deductions of some parameters are as shown in Table 5.

Work input during Stator Assembly

During cycle ride

Table 6 shows Observations and deductions of some parameters for Human Energy Input for stator assembly during cycle ride

Thus unit pulse energy is equivalent to 15570/190.75 = 81.62 kgf-m work
Work intensity while cycling for worker 1 = pulse rate rise/ duration
=20/2.3 = 8.69 pulse /min/min
Work intensity while cycling for worker 2 = pulse rate rise/duration
= 28/2.35
=11.91 pulse /min/min
Average Work intensity while cycling =10.3 pulse /min/min
i.e when work intensity is 10.3 pulse/min/min
1 pulse = 81.62kgf-m

During stator assembly

Work intensity = pulse rate rise/ duration =30/45
= 0.67 pulse /min/min
During stator assembly 1 pulse energy = 81.62 x (0.67/10.3)
= 5.282 kgf-m/pulse

Here one simplifying assumption is made. That assumption is unit pulse energy is proportional to work intensity.
Area under the curve for stator assembly = 4460.42 pulses

Human energy input for stator assembly = 4460.42 x 5.282
= 23559.93 kgf-m
Duration of stator assembly = 45 min =2700 seconds
Energy input per second = 23559.93/2700
= 8.72 kgf-m/sec
H.P. rating = 8.72/75 = 0.1163 H.P.

Normally continuous duty human energy output is reported to be at the rate of 0.13 h.p. [31]

Worker working for stator assembly operation works at 0.1163/0.13 = 0.8946 i.e. 89.46% of his capacity. This results in loss of production = 100 –89.46 = 10.54 %

Work input during Motor Assembly

Work intensity = pulse rate rise/ duration = 20/13.6
= 1.47 pulse/min/min
Thus unit pulse energy is equivalent to 81.62 x (1.47/10.3) = 11.64 kgf-m
And Area under the curve for motor assembly = 1250.92 pulses
Human energy input for motor assembly = 1250.92 x 11.64
= 14560.7 kgf-m
Duration of motor assembly = 13.6 x 60 = 816 seconds
Energy input per sec = 14560.7/816
= 17.84 kgf-m/sec
H.P. = 17.84/75 = 0.23 H.P.

Worker working for motor assembly operation works at 0.23/0.13 = 1.77 i.e.77% more than his capacity. This results in excessive taxing of the worker from the human energy input point of view.

Method 2: In this method the workers were asked to climb up a stairs of building with 2.84 m. height. During this climbing the heart rate was measured at the beginning and at the end and the time of climbing. These observations are shown in Fig. 10. The area under the curve comes out to be 25.2 pulses

Actual work done by the worker during climbing is
Work done = Weight of the worker x height climbed
= 43 x 2.84= 122.12 Kgf-m

Intensity of pulse rise came out to be 80 pulses/min/min. This was rather higher than the pulse rate rise intensity during the two assembly operations. Hence Method 1 i.e. Bicycle ride with weight was executed. Similarly graphs of human energy input for stator and motor assembly of various workers were drawn for the present method and are as shown in Fig. 10. In this way complete analysis of present method of motor assembly was completed.

3.6 Proposed Method For Stator Assembly

The first thing which started after complete analysis of the present method was to determine the dimensions of chair and table according to the workers anthropometric data collected. The dimensions of the chair and table were decided for stator assembly operation and are as shown in Fig 11. Since there is no sitting arrangement for motor assembly , dimensions of motor assembly table only were determined and are as shown in Fig. 12

After analyzing the two-handed flow process chart of the present method it was felt that the motion of two hands is unbalanced and hence an attempt to balance the motions was done in the proposed method. In present method of assembly all the tools and material required for stator assembly were placed on the left hand side of the worker, which resulted in picking every thing by left hand and then transport to right hand. This was eliminated in the proposed method, wherein tools and material was placed in the primary and secondary envelopes of left hand and right hand according to the requirement of left hand and right hand as shown. After deciding the dimensions of chair and table the tools were placed as per the primary and secondary envelopes such that motions of both the hands should be balanced and simultaneous. The work place layout for stator and motor assembly is shown in Fig.13 and Fig. 14 respectively.

Though the workstation was not fabricated, it was arranged as per the dimensions determined and the tools were placed as per the primary and secondary zones as shown in the layouts.

Workers were asked to do the assembly of stator and motor on the new workstations which were ergonomically designed. Method study was carried out and again the two-handed flow process chart was charted. Human energy input was measured and time study was done. Dimensions of chair and table were calculated.

Method Study of Improved Method:

The Workers were asked to assemble the stator and motor on ergonomically designed workstations and two handed process charts were charted for stator assembly as well as motor assembly

Time Study of Improved Method

The stator assembly as well as motor assembly on new workstation was broken into small elements and each element of assembly was measured with stop watch. Total time of assembly was found out for stator as well as motor assembly. The details of time study are shown in Table 8.

Human Energy Input

While the time study was being carried out heart rate of workers assembling stator and rotor was measured simultaneously and is shown in Table 8**.** The graphs were plotted against the time and are shown in fig 15 to 20

3.7 Experimentation

The detailed procedure for performance of test is stated here. The test involves following considerations

- Measurement of related anthropometric features of workers
- Measurement of heart rate of worker during assembly
- Measurement of geometry of tools
- Cost of components of electric motor

Measurement of Related Anthropometric Features of Workers

This includes measurement of anthropometric features of worker in upright sitting posture, standing height, weight age etc. To measure the standing height, worker was asked to stand against a wall with his head straight and leg touching the wall. The height was marked by tri square and pencil on the wall. The distance between floor to marked level will give the standing height. Many seated anthropometric features a,b,c,d,e,f,g,h as shown in fig.1 were measured before the test. The parameters were measured for all the workers and are tabulated in Table 9.

Measurement of Heart rate

The heart rate is measured to find out human energy input of worker. Before the test is carried out i.e. at the start of the work pulse rate was measured manually. Pulse rate was measured by single person, for all the operators, to minimize the error. The work was divided into number of steps or element. Heart rate was measured at the beginning and worker was stopped after every element of work to measure the heart rate as well as elapsed time, till the assembly operation of stator as well as motor was over.

Measurement of Environmental Factors

Different instruments measure the environmental parameters like air speed, temperature and relative humidity. An anemometer with electronic display was used to measure air speed and temperature. A separate electronic meter was used to measure the humidity.

Measurement of geometry of tools

There are numerous tools used for motor and stator assembly. Dimensions of all these tools were measured so as to find out their influence on assembly operation.

3.8 Modification /Conversion Of Experimental Data

The data obtained can be utilized only after modifying or converting into standard form. This can be subdivided into

- Conversion of Anthropometric data
- Conversion of geometric data of chair and table of assembly operation
- Conversion of other variables

The various dimensions recorded in Table 9 were converted into desired form i.e. the dimensionless pi terms The pi term connecting the anthropometric data of a worker involves the independent variables a, b, c, d, e, f, g, h, j, k

$$\pi_1 = \frac{axbxcxdxe}{f\,xgxhxj\,x}$$

Using this formula the value of this pi term for all workers is calculated and was tabulated in Table No 10. After arranging the values of these pi terms in descending order the range of pi term comes out to be 0.69 to 1.23.

Conversion of Geometric data of Chair and Table

The dimensions of Chair and Table for stator assembly are substituted to get the pi term as under

$$\pi_2 = \frac{HxLxW}{HtxLtxWt}$$

$$\pi_2 = \frac{64x38x38}{90x77x108}$$

$= 0.1234$

for motor assembly as there is no sitting arrangement the pi term is modified as

$$\pi_2 = \frac{119x62}{92x92}$$

$= 0.8716$

Relative humidity being dimensionless number is a Pi term $\pi 3$

Conversion of data for tool geometry

π_4 = M x N x C x S x B

$$= \left(\frac{245}{35} x \frac{100}{30}\right) x \left(\frac{40}{20} x \frac{100}{40}\right) x \left(\frac{150}{80}\right) x \left(\frac{150}{40}\right) x \left(\frac{150}{30}\right)$$

$= 4101.562$

The dimensions of various tools are noted and are shown in Fig 4.

Conversion of data for Continuous assembly time

This pi term is a function of continuous assembly time. As the time increases the value of this pi term also increases. It starts from zero and takes largest value.

$$\pi_5 = \frac{gxt^2}{Lt}$$

Where g is the acceleration due to gravity and 'Lt' is the length of table. The values of the pi term are shown in table 10 to15.

Conversion of Other Variables

The response variables i.e. Human Energy and Cost of Partial Assembly should be converted into corresponding pi terms viz. $\pi 6$ and $\pi 7$ respectively.

$$\pi_6 = \frac{HumanEnergy}{Heat}$$

Human energy consumed has been determined from the heart rate measurement. The values computed are shown in Table No. 10 to 15

$$\pi_7 = \frac{Cost\ of\ Partial\ Assembly}{Wages\ of\ labour}$$

The cost of the components used in motor assembly was taken from the accounts department and is shown in Table No. 16 along with the wages paid to labors. And thus this pi term was formed.

4. CONSIDERATIONS: FORMULATION OF APPROXIMATE GENERALIZED EXPERIMENTAL DATA BASED MODEL BY CURVE FITTING METHOD

The relationship between various parameters is unknown. The dependent parameter i.e. pi-6 related to human energy, pi-7 related to cost of assembly bear intricate relationship with remaining pi terms evaluated on the basis of experimentation. The true relationship is difficult to obtain. Present day tools and techniques hints towards regression analysis and predictive neural networks. Such functional relation can explain the joint behavior and variational pattern between independent pi terms and human energy / cost considerations. Any such function obtained will always have the crept in error. In view of this exact value of dependent variable may not conform to the experimental findings. Regression analysis incorporates built in procedure for minimization of such error and hence it is a strong promise for reliance.

The possible relation may be linear, log linear, polynomial with n degrees, linear with products of independent pi terms. In this manner any complicated relationship can be evaluated and further investigated for error. Mapping Buckingham's pi theorem to regression situation

$P_6 = K_0 \times P_1^{K1} \times P_2^{k2} \times P_3^{K3} \times P_4^{K4} \times P_5^{K5}$

This dimensionless statement is easily transformed into linear relationship using log operation.

$\text{Log } P_6 = \log K_0 + K_1 \log P_1 + K_2 \log P_2 + K_3 \log P_3 + K_4 \log P_4 + K_5 \log P_5$

The log linear relationship so obtained is easy to understand and does not damage any facets of original relationship.

Ordinary linear relation stands meaningless in present frame of context because unless operated upon log, we cannot get linear relation. Polynomial relationship would have been excellent provided there is only one independent parameter. In this case we have five independent entities, ruling out the possibility of polynomial relationship i.e.

$Y = a_0 + a_1x + a_2x^2 + a_3x^3 + \text{------------} + a_nx^n$

The product of independent variables can be considered e.g.

$P6 = f(P_1, P_2, P_3, P_4, P_5, P_1P_2, P_2P_3, P_3P_4, \text{-----})$

Though this is a stronger promise over ordinary linear relation, this stands as a weaker structure compared to log linear relation. Log linear relation encompasses not only products but a complicated possinomial combinations of all independent variables in the correct proportion which they ought to be. Technical evaluation of possible models using regression favors log linear relationship for this situation.

4.1 Mathematical Model

The general form of Buckiham's pi theorem can be stated as

$P_6 = K_0 \times P_1^{K1} \times P_2^{k2} \times P_3^{K3} \times P_4^{K4} \times P_5^{K5}$

For convenience of programming and escalating the simility of terms the initial constant K_0 should be replaced with the term sounding e^{K0}. this also is a constant but K_0 from 6,5 is replaced completely by e^{K0} meaning thereby

old $K_0 = e^{\text{new } K0}$

Old K_0 is not referred hereinafter for any purpose. Wherever necessary value of constant can be computed by $e^{\text{new } K0}$ hence equation is modified as

$P_6 = e^{k0} \times P_1^{K1} \times P_2^{k2} \times P_3^{K3} \times P_4^{K4} \times P_5^{K5}$

Obtaining log on both sides we get

$\text{Log } P_6 = K_0 + K_1 \log P_1 + K_2 \log P_2 + K_3 \log P_3 + K_4 \log P_4 + K_5 \log P_5$

This linear relationship now can be viewed as the hyper plane in five dimensional space. To simplify further let us replace log terms by P terms implies

$P_6 = K_0 + K_1 P_1 + K_2 P_2 + K_3 P_3 + K_4 P_4 + K_5 P_5$

This is true linear relationship between P_1------P_5 to reveal P_6.

Applying the theories of regression analysis , the aim is to minimize the error. The term error can now be defined as a difference between experimental findings and value obtained from modeled relation. Say Yc is the computed value of P_6 using regression equation and Ye is the value of same term obtained from experimental data with exactly same values of P_1-----P_5 then

Error (E) = Ye-Yc.

An attempt to minimize error (E) is normally translated to minimization of E^2 conventionally in regression. Implies objective is to search for all possible methods to gain least error, Using differential algebra the point of minimum can be easily obtained by stating

$$\frac{\partial E^2}{\partial x} = 0$$

will ensure the extreme position of error with parameter x which may mean either maximization or minimization. The second differentiation of E^2 awards the confidence whether it is maximum value or minimum value. This entire process can be reduced to finding the values of K_0, K_1, K_2, K_3, K_4, K_5. Once these values are known the relation between independent and dependent variables can be is completely established. Since the aim is to obtain values like K_0, K_1, K_2, K_3, K_4, K_5, it is obvious that square of error should be differentiated w.r.t. the constant of equation

$E = Yc - Ye$

$= (K_0 + K_1 P_1 + K_2 P_2 + K_3 P_3 + K_4 P_4 + K_5 P_5 - Ye)$

implies

$E^2 = (K_0 + K_1 P_1 + K_2 P_2 + K_3 P_3 + K_4 P_4 + K_5 P_5 - Ye)^2$

Differentiating w.r.t K_0

$$\frac{\partial E^2}{\partial K_0} = 2\ (K_0 + K_1 P_1 + K_2 P_2 + K_3 P_3 + K_4 P_4 + K_5 P_5 - Ye) \qquad =0$$

differentiating w.r.t. K_1 we get

$$\frac{\partial E^2}{\partial K_1} = 2\ (K_0 + K_1 P_1 + K_2 P_2 + K_3 P_3 + K_4 P_4 + K_5 P_5 - Ye) \times P_1$$

$$= 2\ (K_0P_1 + K_1P_1^2 + K_2P_1P_2 + K_3P_1P_3 + K_4P_1P_4 + K_5P_1P_5 - YeP_1) =0$$

$$\frac{\partial E^2}{\partial K_2} = 2\ (K_0P_2 + K_1 P_1 P_2 + K_2 P_2^2 + K_3 P_2P_3 + K_4 P_2 P_4 + K_5 P_2 P_5 - Ye\ P_2) =0$$

$$\frac{\partial E^2}{\partial K_3} = 2\ (K_0P_3 + K_1 P_1 P_3 + K_2 P_2 P_3 + K_3 P_3^2 + K_4 P_3 P_4 + K_5 P_3 P_5 - Ye\ P_3) =0$$

$$\frac{\partial E^2}{\partial K_4} = 2\ (K_0P_4 + K_1 P_1 P_4 + K_2 P_2 P_4 + K_3 P_3 P_4 + K_4 P_4^2 + K_5 P_4 P_5 - Ye\ P_4) =0$$

$$\frac{\partial E^2}{\partial K_5} = 2\ (K_0P_5 + K_1 P_1 P_5 + K_2 P_2 P_5 + K_3 P_3 P_5 + K_4 P_4 P_5 + K_5 P_5^2 - Ye\ P_5) =0$$

All equations are equated to zero and hence the constant term 2 can be dropped. In matrix form it can be written as

$$\begin{vmatrix} 1 & P_1 & P_2 & P_3 & P_4 & P_5 \\ P_1 & P_1^2 & P_1P_2 & P_1P_3 & P_1P_4 & P_1P_5 \\ P_2 & P_1P_2 & P_2^2 & P_2P_3 & P_2P_4 & P_2P_5 \\ P_3 & P_1P_3 & P_3P_2 & P_3^2 & P_3P_4 & P_3P_5 \\ P_4 & P_1P_4 & P_4P_2 & P_4P_3 & P_4^2 & P_4P_5 \\ P_5 & P_1P_5 & P_5P_2 & P_5P_3 & P_5P_4 & P_5^2 \end{vmatrix} \times \begin{vmatrix} K_0 \\ K_1 \\ K_2 \\ K_3 \\ K_4 \\ K_5 \end{vmatrix} - \begin{vmatrix} Ye \\ YeP_1 \\ YeP_2 \\ YeP_3 \\ YeP_4 \\ YeP_5 \end{vmatrix} = \begin{vmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{vmatrix}$$

Replacing symbol Ye by Z and shifting it to right we get

$$\begin{vmatrix} 1 & P_1 & P_2 & P_3 & P_4 & P_5 \\ P_1 & P_1^2 & P_1P_2 & P_1P_3 & P_1P_4 & P_1P_5 \\ P_2 & P_1P_2 & P_2^2 & P_2P_3 & P_2P_4 & P_2P_5 \\ P_3 & P_1P_3 & P_3P_2 & P_3^2 & P_3P_4 & P_3P_5 \\ P_4 & P_1P_4 & P_4P_2 & P_4P_3 & P_4^2 & P_4P_5 \\ P_5 & P_1P_5 & P_5P_2 & P_5P_3 & P_5P_4 & P_5^2 \end{vmatrix} \times \begin{vmatrix} K_0 \\ K_1 \\ K_2 \\ K_3 \\ K_4 \\ K_5 \end{vmatrix} = \begin{vmatrix} Z \\ ZP_1 \\ ZP_2 \\ ZP_3 \\ ZP_4 \\ ZP_5 \end{vmatrix}$$

Applying summation over all experimental findings we get

$$\begin{vmatrix} n & \sum P_1 & \sum P_2 & \sum P_3 & \sum P_4 & \sum P_5 \\ \sum P_1 & \sum P_1^2 & \sum P_1P_2 & \sum P_1P_3 & \sum P_1P_4 & \sum P_1P_5 \\ \sum P_2 & \sum P_1P_2 & \sum P_2^2 & \sum P_2P_3 & \sum P_2P_4 & \sum P_2P_5 \\ \sum P_3 & \sum P_1P_3 & \sum P_3P_2 & \sum P_3^2 & \sum P_3P_4 & \sum P_3P_5 \\ \sum P_4 & \sum P_1P_4 & \sum P_4P_2 & \sum P_4P_3 & \sum P_4^2 & \sum P_4P_5 \\ \sum P_5 & \sum P_1P_5 & \sum P_5P_2 & \sum P_5P_3 & \sum P_5P_4 & \sum P_5^2 \end{vmatrix} \times \begin{vmatrix} K_0 \\ K_1 \\ K_2 \\ K_3 \\ K_4 \\ K_5 \end{vmatrix} = \begin{vmatrix} \sum Z \\ \sum ZP_1 \\ \sum ZP_2 \\ \sum ZP_3 \\ \sum ZP_4 \\ \sum ZP_5 \end{vmatrix}$$

Using array names viz P,K and Z we get

$$[P]\times[K]=[Z]$$

implying

$$[K]=[P]^{-1}[Z]$$

After obtaining all the summation indicated in array P and array Z the statement of the problem can be computed. After inverting array P and post multiplying with array Z we get all the required values i.e values of K_0, K_1, K_2, -------K_5 are known after this process.

The value of associated error now can be found out. Once the values of all k are known the computed value Yc can be generated. Ye is the readily available from experimental data, hence Root Mean Square error can be computed as follows.

$$\text{R.M.S. Error} = \sqrt{\frac{\sum E^2}{n}}$$

$$= \sqrt{\frac{\sum (Yc - Ye)^2}{n}}$$

where n is the number of experiments carried.

4.2 Model Options

This experimentation is for electrical motor assembly. Even the single exhibit of entire motor assembly sounds appreciable. Technically stator assembly is carried out first and contributes major proportions to entire assembly. That is why stator assembly must have separate consideration and while investigating motor assembly earlier stator assembly should be amalgamated. In short stator assembly , remaining assembly when stator is ready and entire motor assembly from basic components are felt necessary to understands the relationship between human energy, cost of assembly and governing ergonomic and ambient factors. This calls for similar investigation for three situations.

1. $P_7 = f(P_1$,----------$P_6)$ For stator
2. $P_7 = f(P_1$,----------$P_6)$ For Motor
3. $P_7 = f(P_1$-----------$P_6)$ Combined

Out of the affecting dimensionless terms ranging from P_1 to P_6, some terms do not show large variation. The cognitive effect for such parameters can be approximated to their mean and hence this effect can be temporarily considered to be constant. Though this is not totally true, such consideration provides an avenue to understand elaborate effect of real contributors. Variation between minimum and maximum for P_1 ------P_6 indicates larger variation for P_1,P_5,P_6 and minimum variation of P_2,P_3,P_4. Thus an alternative model has been tried considering effect of P_2,P_3 and P_4 as constants. This will reveal detailed contribution of left over terms, which are P_1,P_5 and P_6

1. $P_7 = f(P_1, P_5, P_6)$ for Stator
2. $P_7 = f(P_1, P_5, P_6)$ for Motor
3. $P_7 = f(P_1, P_5, P_6)$ for combined assembly

The cost consideration and human energy consumption have some relevance. Disregarding cost considerations human energy displays distinguished existence in this frame of reference. The contributing parameters for the cost may vary with technology, skill set of workers, conducive environment. Contrary energy requirement for an assembly will have similar effectors; still declaring partial independence from cost considerations. The experimentation can be viewed as devoid of cost and obvious output parameters i.e. energy can be interpreted as function of P1,P2,P3,P4,P5 this generated a scaled down model as

1. $P_6 = f(P_1, P_2, P_3, P_4, P_5)$ for Stator assembly
2. $P_6 = f(P_1, P_2, P_3, P_4, P_5)$ for motor assembly
3. $P_6 = f(P_1, P_2, P_3, P_4, P_5)$ for combined assembly

In earlier models some pi terms were omitted for observing detailed effect of large variation terms. The situation in energy model remains unchanged. This means by and large small variation parameters should be disregarded and profound effect of large variation terms must be studied. The similar stub models of energy can now be built as

1. $P_6 = f(P_1,P_5)$ for Stator assembly
2. $P_6 = f(P_1,P_5)$ for Motor assembly
3. $P_6 = f(P_1,P_5)$ for Combined assembly

All such models are worked out with traditional assembly process. This process was later amended and new workstation layout and methodology was devised. This was done with an expectation to increase productivity and reduce energy consumption. The dependence in these two different situations is evaluated. The coefficients corresponding to independent variables should decline in improved situation. This provides an opportunity to study differential effects of contributing parameters. In brief sensitivity of models to issues under consideration can now be evaluated.

The experimental findings for improved situation are tabulated separately. All the models recommend for traditional assembly process are rebuilt for new situation. This will enable to have two relations between dependent and independent parameters ruling under two different situations. Hence twelve new models are formed as under.

Cost Model

1. $P_7 = f\ (P_1, P_2, P_3, P_4, P_5, P_6)$ For Stator assembly
2. $P_7 = f\ (P_1, P_2, P_3, P_4, P_5, P_6)$ For Motor assembly
3. $P_7 = f\ (P_1, P_2, P_3, P_4, P_5, P_6)$ For Combined assembly

Stubbed Cost Model

4. $P_7 = f\ (P_1, P_5, P_6)$ for Stator
5. $P_7 = f\ (P_1, P_5, P_6)$ for Motor
6. $P_7 = f\ (P_1, P_5, P_6)$ for combined assembly

Energy Model

7. $P_6 = f\ (P_1, P_2, P_3, P_4, P_5)$ for Stator assembly
8. $P_6 = f\ (P_1, P_2, P_3, P_4, P_5)$ for motor assembly
9. $P_6 = f\ (P_1, P_2, P_3, P_4, P_5)$ for combined assembly

Stubbed Energy Model

10. $P_6 = f\ (P_1, P_5)$ for Stator assembly
11. $P_6 = f\ (P_1, P_5)$ for Motor assembly
12. $P_6 = f\ (P_1, P_5)$ for Combined assembly

4.3 Computational Algorithm

One single model can be easily handled using top down programming. Such single flow program has the same concept that is useful for remaining models. Since fundamentally all these models are polymorphic about the central idea of regression; it is possible to bundle them together with an independent behavior. A program in C is written to accomplish the task Log liner relation is handled by main function.. These steps are summarized in the flow chart shown in chart No.1. Results obtained are shown in Table No. 17 to Table No.20.

4.4 Ann Simulation Of Models

Intricate behavior of output parameters can be studied using simulation techniques. In fact an approximate behavior can be explained using regression analysis. The true intricacies take the shape of non-linear behavior. Regression fails to explain any such deviation from assumed relationship. Multiplicity of behavior cannot be combined in regression because it generates complicated relationship , which may not be resolved mathematically. In order to understand the fine behavior of output parameters, simulation using ANN was the best proposition. The neural network used in this case was predictive in nature. It was range bound for all input factors. If 12 different situations considered for modeling are to be simulated the input factors vary from 2,3,5, and 6. Varying number of inputs made it difficult to construct a single network. This imposed difficulty was overcome by considering common characters of large input system. The scaled down (stub) models could be easily accommodated by first building reasonably sufficient network to support all situations. Maximum inputs in this case were limited to six. A single output parameter was obtained. In neural network terminology total Input output cells were 7. A network with three hidden layers was reasonable to simulate. Numbers of cells in hidden layer selected were 15. Mathematically both these numbers – number of layers and cells are justified in present day theories of neural network.

All the input parameters were scaled down between zero and one using their maximum and minimum values. This is the requirement to make the data flow on neural network. The values of synaptic weights and thresholds were chosen randomly between zero and one. The data was iterated forward and backward for more than one lack iterations or to achieve accuracy at sixth place of decimal (whichever was earlier). The weights and threshold were corrected in every iteration. The values of weights and thresholds obtained at the end were matured values and indicated the end of learning process of the network.

Thus it was very easy to answer what will be the output parameter if input factors are known. A separate program was written for this prediction. This program simulates the structure of entire network using final values of weights and thresholds. It carries out the single iteration using scaled values of input factors to generate the scaled values of output parameter. This scaled value is further translated to its physical value by reverse scaling calculations. In this way once the network has gone through the learning process, it is capable of predicting output parameters Viz. Value addition and human energy input immediately. The complex relationship in manipulation of the output is not truly known but the numerical results are obtainable. Moreover these results are least affected by discrepant error.

The adjustable neural network was tailored for twelve different situations earlier modeled using Buckingham's pi theorem and handled using regression analysis. The separate network was not required for situation after improvement but it was essential to train the network about changed relationship between input output parameters after incorporating improvements in assembly system.

Both the situations were truly viewed and difference in behavior could be easily computed. Table 21 : Sample Run of ANN Model for Stator is shown in Table 21 Threshold values of stator model during sample run are shown in Table 22 and Weights of Stator Model during Sample Run are shown in Table 23.

5. OPTIMIZATION OF MODELS

The parametric interdependence of input factors and their exhibit -able effect on value addition or human energy can be studied using ANN simulation process. The question still continues is what best value of output parameter is attainable with varying conditions in assembly operation? Obviously the aim was to find maximum value addition by selecting proper inputs those could really exist. At the same time such a set of parameters should minimize the human energy input, which stands as a second objective..

Studies revealed the range of variation for every input factor. The most satisfying value on this range for each parameter has to be selected which would push the output in favorable direction. This was achieved using range bound optimization of input parameters. The mini-max principle was used to find these results. This provides the best set of working factors and enables us to upgrade productivity at minimal cost. Since all input factors had their own definite range, the problem could be translated into mini-max problem using zero one programming. Optimal values of contributing factors were calculated for all twelve situations before and after improvement. Results obtained are tabulated in Table 24 & 25

6. SENSITIVITY ANALYSIS OF MODELS

The best sets of working parameters were obtained using optimization method. This is a situation which industry would like to maintain. The working factors are different at all the times and such ideal situation may not be satisfied. The governing factors are bound to change, typically those from environment. Such parameters must be monitored towards their optimal value for achieving the better productivity. Some of the factors have sparing effect and other have dominating effect. Even if this situation cannot be maintained at ideal point, it is essential to understand which factor has stronger effect on value addition and human energy input. This helps the organization to exercise stricter control on dominating factors. The sensitivity analysis was carried out for this purpose. The ten percent variation of the single factor on positive and negative side was introduced and the difference in output parameter was calculated. The ratio of variation of output parameter to variation of input factors is the measure of sensitivity. Such sensitivity was computed for each factor separately. The process was repeated for all the twelve models before and after improvement. This provides an insight to monitor the conditions in best direction of productive situation.

7. NOMOGRAMS

Nomograms are plotted to represent the functions of the form Y= f(X1,X2). In present experimentation stub models fulfill this requirement. Value addition and human energy input can be interpreted using anthropometric data and continuous time of assembly. Nature of the curve is diverging curvilinear lines. This indicates large value increase in output at lower values of x with small increase in y variable. Nomograms can help us in deciding the direction of maximization or minimization. Nomograms cannot provide support to multidimensional problem. Only two variables can be considered. Most effective parameters are considered here. This helps in identifying the partial dependence of output. Interdependence of input parameters at constant output value can also be studied. Nomograms obtained are shown in Fig. 23 to Fig. 32

8. RESULTS

The modified method has definitely improved the productivity (Table 26 &27). It has also reduced the human energy input of the workers. Reducing human energy input made workers comfortable. Various parameters were identified which contribute to the assembly phenomenon. The importance of these parameters over one another was obtained.

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Mathematical procedures, computer techniques, artificial neural network, controls using microcontrollers are amongst the recent work. Human behavior, its limitations and motion and power transformation with understanding from amongst present assignments. Worked with around 10 different industrial setup with the viewpoint of analysis and later optimization and automation.