# Advancement of model for examination of temperature impact in radial ball bearing utilizing grid technique for DAMM investigation

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ABSTRACT

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*The main objective of the paper on Radial Ball Bearing (RBB) to lessen the warmth age on bearing surface and bolster spiral and hub stacking and it can stay away from the warmth age by grating, the wear and force misfortunes brought about by the relative movement between the metal materials. Warmth is produced by the heap position in the bearing framework, which cause the temperature expanding inside the bearing surface and expanded temperatures may offer ascent to untimely disappointments. Along these lines, it is essential to figure the temperature in the orientation because of burden position. Here a summed up model is created utilizing Dimensional Analysis of Matrix Method (DAMM) to assess dimensionless connection between's the reaction and result parameters for the appraisal of warmth age on the bearing surface on a created test rig. Reaction Surface Methodology (RSM) is utilized for the experimentation and investigate the reliance of different factors on the warmth age of these course. A numerical investigation created in the examination demonstrated the viability of DAMM model along side the adequacy of burden position for location of warmth age on spiral metal roller surface.*

## 1. Introduction

The idea of moving movement is known and utilized for a large number of years. The Assyrians (ca. 1100 BC) utilized rollers under the sledges to convey monstrous stones. Straight forward types of moving component direction were first utilized during the Roman human advancement. Leonardo da Vinci (1452-1519 AD) understood that the balls or rollers ought to be avoided at all costs from one another to diminish erosion. The creator introduced the essential development of present day moving component orientation in his Codex Madrid. The general use didn‘t happen until the Industrial in surgency Nowadays, moving component direction are one of the most utilized parts in mechanical applications. Across different businesses, they play a significant and successful job. A typical family contains around 150 moving component orientation in various types of hardware. A normal vehicle contains over a 100 moving component direction. A typical moving component bearing comprises of an inward and external ring and various moving components. The two rings have furrows or raceways to manage the moving components. The moving components are isolated from one another by a pen. A modest quantity of freedom between the inward and external ring is for the most part given. To lessen the erosion and wear in the moving contacts, the bearing is greased up.

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Being especially basic segments, the usefulness of moving component bearing is generally fundamental for the machine‘s activity. They have been the subject of research for over 100 years. This examination centers around the bearing materials, producing, disappointment, grease, elements, and so on. The information is incompletely accessible in the open writing and halfway secured by the bearing producers. Dimensional examination includes a dimensional model examination of acting amounts in the explored procedure. It empowers one to decide, in a straightforward mathematical way, dimensionless comparability criteria and useful relations, spoke to among them by a measure condition. Further, it empowers the transformation of physical amounts into different central arrangements of estimating units, the change of estimating units and different techniques. In displaying and test, its principle work is to lessen the measure of free factors, to improve the arrangement and to sum up the outcomes thereof. It can turn into a successful technique, particularly if a total scientific model of the explored procedure isn‘t known. This is a technique, straight forward from the common sense perspective, which doesn‘t empower either tackling an issue totally or uncovering significant internal couplings of an examined wonder. Nonetheless, it is an exceptionally successful methods for acquiring a thought regarding the conduct of a marvel if neither its total numerical nor physical depictions are known. As a rule, it is a significant physical apparatus in each increasingly entangled physical, logical or mechanical trial. The primary elements of dimensional investigation are the accompanying.

- Determination of the number and type of dimensionless amounts which speak to the closeness criteria.
- Reduction of the numbered free factors in a test, improvement of the arrangement and speculation of its outcomes.
- Conversion of the fundamental arrangement of units of the estimation,
- Conversion of physical amounts into another fundamental arrangement of units of estimation,
- Determination of useful relations in situations where the solver doesn’t know progressively nitty gritty data of the physical rule of the examined marvel and no total numerical depiction of the phenomenon is known.

In application of dimensional analysis, the highest efficiency is reached in its combination with general physical ideas obtained by a solver directly from experiments. The depth of previous knowledge of the physical principles of the investigated phenomenon can influence and extend considerably the possibilities of the dimensional analysis.

Buckingham [1] has finished and methodicallly tended to the dimensional investigation and similitude. At about a similar time as the German architect, a dimensional investigation was created. Bruwell gathered the pole‘s circles under the states of the mid year field for various dynamic charging methods of long coats. This thought was stretch out by William Froude by relating the demonstrating of open channel stream and real body yet more significantly the connection between drag of models to real ships. While most of the commitments were finished by thermo–liquid folks the idea of the comparable or comparative proliferated to other fields. Aiméem Vaschy, a German Mathematical Physicist proposed utilizing similitude in electrical building and recommended the Norton circuit identicalness hypotheses. Rayleigh presumably was the first who utilized dimensional investigation to acquire the connections between the physical quantities. Osborne Reynolds [2] was the first to infer and utilize dimensionless parameters to break down exploratory information. Cameron and Wood [3] utilized Southwell‘s Relaxation technique to settle the Reynolds Equation for limited full diary course running from L/D = ∞ to ¼.

Wilcock [4] in a progression of examinations with 8-in. diary orientation found that their exhibition was truly adjusted when worked in the fierce system. Petrusevich [5] acquired the answers for film thickness in gears which incorporated the versatility conditions and, all the while, found the fundamental and run of the mill state of elasto hydrodynamic pressure profiles.

Ocvirk [6,7] gave a point by point and full answer for the issue of short heading. It is a generally basic, conservative, and rich arrangement which for explanatory controls is without peer. What‘s more, in spite of its mark of vastly short, it is essentially substantial to L/D proportions of up to ½, which is the structure scope of most current orientation.

Sommerfeld and Walter [8] used a Gaussian calculation for fathoming limited contrast conditions for both 3600 and 1800 circular segments.

The principal utilization of current PCs in the arrangement of the limited Reynolds condition utilizing the best possible limit conditions was made by Pinkus [9] He acquired the arrangements for round about as well as for curved and three-flap heading for L/D proportions running from 1.5 to 0.25, just as for limited course for different bends and (R2/R 1) proportions. Bruwell utilized a similar methodology as Swift, to get the answers for the progressively stacked direction dependent on the short bearing hypothesis. Raimond and Boyd [10] gave the answer for full and incomplete diary course for L/D proportions of 0.25, 0.5, and 1 for incompressible liquids and further more introduced the outcomes for gas heading for L/D proportions of 0.5, 1, 2. Gross amassed an arrangement of limited gas bearing answers for different working conditions.

A few specialists made an endeavor to comprehend the warm conduct of the bearing during its working condition. Bossmanns and Tu [11,12] built up a warm model of a fast shaft to ascertain the warmth age logically in rakish contact metal ball by considering the impact of preload, rotational speed and oil. In this way, Li and Shin [13] set forward a coordinated thermodynamic model by utilizing limited component technique for rapid axles and coupled it with axle dynamic model through warm extension just as warmth age of the entire framework. Jin et al. [14] decided the pace of warmth age in bearing by considering the outside heap of the machine device and rotational speed. Later, Moorthy and Raja [15] proposed an explanatory model to assess the warmth age in rakish contact bearing by thinking about the change in polar leeway after get together and during turn. In this manner, saw that at speeds (>2000 rpm), heat age from the proposed model has insignificant deviation contrasted with trial esteems. Takabi and Khonsari [16] contemplated tentatively and scientifically about the development of temperature in a profound section metal ball concerning time for various rotational speed and burden in an oil-shower oil framework. Subsequently, the anticipated estimations of temperature of the oil, external race and lodging are seen as in great concurrence with those deliberate tentatively. Mitrovic et al. [17] displayed the impact of initiated temperature on warm extension and parameters of outspread metal roller. Besides, limited component examination is done for spiral metal ball to figure bearing parameters at a few activity temperatures. Afterward, finished up about the created method by explaining the issues identified with the running condition of holding on for regard to ideal activity temperature. Dong et al. [18] tentatively estimated the temperature field circulation by utilizing fiber Bragg grinding sensors to comprehend the purposes for the warmth age in bearing. Not with standing that, creator broke down the warm field dissemination by performing recreation in ANSYS. Li [19] did trial examination on warm qualities of a shaft bearing framework. Besides, utilized the thermo-mechanical coupling model and warmth move model to dissect the parameters like applied power, preload, greasing up state, surface morphology and rotational speed numerically. The huge impact on the high rotational rates, preload oil thickness, and warmth move coefficient on warm disappointment of the bearing is uncovered.

## 2. Definition of Mathematical Model

By utilizing Buckingham π-Method, In the present examination, 24 parameters are considered during the examination like Reaction power (Fr), Acceleration because of gravity (g), Shaft speed (n), Power (P), Heat produced in the bearing (Q), Surface temperature of the bearing (Ta), Load conveying limit (N), Frequency of the bearing (Fb), Dynamic thickness (μ), Bearing Size (Dball), Clearance of metal ball (Cball), Thermal conductivity (K), Convective warmth move coefficient (H), Shaft thickness (ρ), Flexural unbending nature (EJ), Moment of latency (I), Stiffness (s), Thermal conductivity (Kref), Shaft speed (nref), Load conveying limit (nref), Frequency of the bearing (Fbref), Bearing size (Dball ref), Dynamic consistency (μref), Temperature beginning (Tinitial). While in different techniques, Non dimensionless numbers are hard to process. In this way, initially, the bearing parameters are read for breaking down the bearing qualities are condensed incorporating with their measurements lastly π-terms are assessed.

## 3. Assessing π-terms

The π-terms are assessed by considering four rehashing factors which are Heat move coefficient (h), Heat Generated in the bearing (q), Thermal conductivity (k), Power (p). Thusly the quantity of π-terms is 20. The 20 π-terms are spoken to regarding conditions are given below. The conditions are settled by Buckingham pi-hypothesis and the conditions (1-20) are in lattice structure is given in condition (21). The grid B1 is the arrangement framework and network An is unique dimensional lattice and in which AS is a sub framework of definitive amounts and AZ is the lingering sub framework. The arrangement network (B1) as far as conditions are given underneath (conditions 22-29).

$$\Pi_1 = h^{a1}q^{b1}k^{c1}p^{d1}.Fr \quad (1)$$

$$\Pi_2 = h^{a2}q^{b2}k^{c2}p^{d2}.g \quad (2)$$

$$\Pi_3 = h^{a3}q^{b3}k^{c3}p^{d3}.n \quad (3)$$

$\Pi_4 = h^{a4}q^{b4}k^{c4}p^{d4}.Ta$ (4)

$\Pi_5 = h^{a5}q^{b5}k^{c5}p^{d5}.W$ (5)

$\Pi_6 = h^{a6}q^{b6}k^{c6}p^{d6}.fb$ (6)

$\Pi_7 = h^{a7}q^{b7}k^{c7}p^{d7}.\mu$ (7)

$\Pi_8 = h^{a8}q^{b8}k^{c8}p^{d8}.Dball$ (8)

$\Pi_9 = h^{a9}q^{b9}k^{c9}p^{d9}.T_{initial}$ (9)

$\Pi_{10} = h^{a10}q^{b10}k^{c10}p^{d10}.fb_{ref}$ (10)

$\Pi_{11} = h^{a11}q^{b11}k^{c11}p^{d11}.\mu_{ref}$ (11)

$\Pi_{12} = h^{a12}q^{b12}k^{c12}p^{d12}.Dball_{ref}$ (12)

$\Pi_{13} = h^{a13}q^{b13}k^{c13}p^{d13}.k_{ref}$ (13)

$\Pi_{14} = h^{a14}q^{b14}k^{c14}p^{d14}.n_{ref}$ (14)

$\Pi_{15} = h^{a15}q^{b15}k^{c15}p^{d15}.N_{ref}$ (15)

$\Pi_{16} = h^{a16}q^{b16}k^{c16}p^{d16}.\rho$ (16)

$\Pi_{17} = h^{a17}q^{b17}k^{c17}p^{d17}.E_J$ (17)

$\Pi_{18} = h^{a18}q^{b18}k^{c18}p^{d18}.I$ (18)

$\Pi_{19} = h^{a19}q^{b19}k^{c19}p^{d19}.S$ (19)

$\Pi_{20} = h^{a20}q^{b20}k^{c20}p^{d20}.C_{ball}$ (20)

$B_1 = -[((A_Z)^T)^{-1} * (B_Z)^T]$ (21)

Where

B is solution matrix, $A_S$ is a sub matrix of decisive quantities and $A_Z$ is the residual sub matrix.

Here,

Total number of dimensional quantities (M) = 24

Fundamental dimensional quantities (N) = 4

If we apply Buckingham Pi-theorem for this data, We get

Total number of Dimensionless quantities = M-N= 20

Total Number of π-terms = 20

And taking H, Q, K, P as repeating variables

Among every one of these conditions π4 & π9, π6 & π10, π 7 & π 11, π8 & π12 and π3 & π14 are same. In this manner 13 π-terms are affecting the qualities of bearing.

Thusly, the marvel of warmth age in the bearing framework can be communicated as,

$$\pi_1 = f(\pi_2, \dots \dots \dots \dots \dots \dots \dots \dots \dots \pi_{20}) \quad (22)$$

**Table 1**

Twenty dimensionless π- terms.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Fr** | **g** | **n** | **Ta** | **W** | **fb** | **µ** | **Dball** | **Tinitial** | **fB ref** | **µ ref** | **Dballref** | **k ref** | **n ref** | **N ref** | **ρ** | **EJ** | **I** | **S** | **Cball** | **h** | **q** | **k** | **p** |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | -1 | 1 | 0 |
| 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | -1 | -2 |
| 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | -1 |
| 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | 0 | 2 | -1 |
| 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | -1 | 1 | 0 |
| 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | -1 |
| 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -3 | -2 | 3 | 1 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | -1 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | 0 | 2 | -1 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | -1 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -3 | -2 | 3 | 1 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | -1 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | -1 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | -1 | -1 | 1 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | -5 | -3 | 5 | 2 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | -5 | -7 | 5 | 4 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 4 | 0 | -4 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | -2 | -1 | 2 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | -1 | 0 |

Since, the quantity of dimensionless parameters is still more. In this way, they are additionally streamlined by the accompanying tasks given in Table 2.

Assuming constant,

$$k = f(\pi_a, \pi_b, \pi_c, \pi_d, \pi_e, \pi_f, \pi_g, \pi_h, \pi_{13})$$

Where '$k$' represent the constant variables which don't vary during the experimentation. Therefore, the equation (22) is rewritten as,

$$\pi_1 = f(k, \pi_i, \pi_j, \pi_k) \quad (23)$$

The derived $\pi$ terms for heat generation (Q) can be formulated using power law as,

$$\pi_1 = k\, \pi_i^{c1} \pi_j^{c2} \pi_k^{c3} \quad (24)$$

## 4. Development of Correlation between Dimensionless Parameters by Regression Analysis

The solution of governing equation (24) is solved by multiple regression analysis technique and the constants $c_0$, $c_1$, $c_2$, $c_3$ are obtained by following mathematical operations. Among 'n' experiments to be performed, the response of $i^{th}$ experiment is calculated as,

$$y_i = c_0 + c_1 x_{i1} + c_2 x_{i2} + c_3 x_{i3} \quad (25)$$

Therefore, sum of all the 'n' experiments is written as,

$$\sum_{i=1}^{n} y_i = n\, c_0 + c_1 \sum_{i=1}^{n} x_{i1} + c_2 \sum_{i=1}^{n} x_{i2} + c_3 \sum_{i=1}^{n} x_{i3} \quad (26)$$

To determine the four unknowns we require four simultaneous equations, so the other equations are obtained by multiplying $x_{i1}, x_{i2}, x_{i3}$ one by one separately to equation (26) as follows,

$$\sum_{i=1}^{n} y_i x_{i1} = n\, c_0 \sum_{i=1}^{n} x_{i1} + c_1 \sum_{i=1}^{n} x_{i1} x_{i1} + c_2 \sum_{i=1}^{n} x_{i2} x_{i1} + c_3 \sum_{i=1}^{n} x_{i3}\, x_{i1} \quad (27)$$

$$\sum_{i=1}^{n} y_i x_{i2} = n\, c_0 \sum_{i=1}^{n} x_{i2} + c_1 \sum_{i=1}^{n} x_{i1} x_{i2} + c_2 \sum_{i=1}^{n} x_{i2} x_{i2} + c_3 \sum_{i=1}^{n} x_{i3}\, x_{i2} \quad (28)$$

$$\sum_{i=1}^{n} y_i x_{i3} = n\, c_0 \sum_{i=1}^{n} x_{i3} + c_1 \sum_{i=1}^{n} x_{i1} x_{i3} + c_2 \sum_{i=1}^{n} x_{i2} x_{i3} + c_3 \sum_{i=1}^{n} x_{i3}\, x_{i3} \quad (29)$$

Equations (27) to (29) are solved simultaneously for the unknowns. Therefore, after determining the unknowns, equation (24) is used as model equation to obtain the heat generation in a bearing system.

## 5. Response Surface Methodology

RSM is a variety of numerical and verifiable procedures that are significant for exhibiting and examining circumstances in which fervor responses are affected by a couple of factors and are planned to propel this response (Oktem et al., 2005; Palanikumar, 2008). RSM likewise evaluates the connection between in any event one anticipated

**Table 2**
Simplified dimensionless variables.

| $\pi_{simplified}$ | | | | | |
|---|---|---|---|---|---|
| $\pi_a = \frac{\pi_3}{\pi_{14}}$ | $\pi_b = \frac{\pi_5}{\pi_{15}}$ | $\pi_c = \frac{\pi_6}{\pi_{10}}$ | $\pi_d = \frac{\pi_8}{\pi_{12}}$ | | $\pi_e = \frac{\pi_{16}}{\pi_{17}}$ |
| $\pi_f = \frac{\pi_4}{\pi_9}$ | $\pi_g = \frac{\pi_7}{\pi_{11}}$ | $\pi_h = \frac{\pi_{18}}{\pi_{19}}$ | $\pi_i = \frac{\pi_2}{\pi_{20}}$ | | $\pi_j = \frac{\pi_{18}}{\pi_{19}}$ |
| $\pi_k = \frac{\pi_{16}}{\pi_{17}}$ | | | | | |

**Table 3**
Coded values and real values of the variables.

| Sl. No. | Load (L) | | Load Position (LP) | | Speed (S) | |
|---|---|---|---|---|---|---|
| | Coded | Real | Coded | Real | Coded | Real |
| 1 | –1 | 1.00 | –1 | 0.25 | 0 | 1600 |
| 2 | 1 | 2.50 | –1 | 0.25 | 0 | 1600 |
| 3 | –1 | 1.00 | 1 | 0.75 | 0 | 1600 |
| 4 | 1 | 2.50 | 1 | 0.75 | 0 | 1600 |
| 5 | –1 | 1.00 | 0 | 0.50 | –1 | 800 |
| 6 | 1 | 2.50 | 0 | 0.50 | –1 | 800 |
| 7 | –1 | 1.00 | 0 | 0.50 | 1 | 2400 |
| 8 | 1 | 2.50 | 0 | 0.50 | 1 | 2400 |
| 9 | 0 | 1.75 | –1 | 0.25 | –1 | 800 |
| 10 | 0 | 1.75 | 1 | 0.75 | –1 | 800 |
| 11 | 0 | 1.75 | –1 | 0.25 | 1 | 2400 |
| 12 | 0 | 1.75 | 1 | 0.75 | 1 | 2400 |
| 13 | 0 | 1.75 | 0 | 0.50 | 0 | 1600 |
| 14 | 0 | 1.75 | 0 | 0.50 | 0 | 1600 |
| 15 | 0 | 1.75 | 0 | 0.50 | 0 | 1600 |

**Table 4**
Observed values for performance characteristics.

| Std. Order | Run Order | Factors | | | Responses | |
|---|---|---|---|---|---|---|
| | | Load, L (kg) | Load Position, LP (m) | Speed, S (RPM) | $T_2$ (°C) | $T_3$ (°C) |
| 1 | 1 | 1.00 | 0.25 | 1600 | 36.4 | 36.7 |
| 2 | 4 | 2.50 | 0.25 | 1600 | 38.4 | 37.8 |
| 3 | 9 | 1.00 | 0.75 | 1600 | 46.5 | 45.5 |
| 4 | 15 | 2.50 | 0.75 | 1600 | 46.8 | 46.4 |
| 5 | 6 | 1.00 | 0.50 | 800 | 39.2 | 38.8 |
| 6 | 5 | 2.50 | 0.50 | 800 | 39.2 | 38.2 |
| 7 | 14 | 1.00 | 0.50 | 2400 | 38 | 37.6 |
| 8 | 7 | 2.50 | 0.50 | 2400 | 40 | 39.2 |
| 9 | 2 | 1.75 | 0.25 | 800 | 36 | 35.1 |
| 10 | 11 | 1.75 | 0.75 | 800 | 45.6 | 45.1 |
| 11 | 12 | 1.75 | 0.25 | 2400 | 38.2 | 37.6 |
| 12 | 13 | 1.75 | 0.75 | 2400 | 49.2 | 48.8 |
| 13 | 3 | 1.75 | 0.50 | 1600 | 43.4 | 42.9 |
| 14 | 10 | 1.75 | 0.50 | 1600 | 42.9 | 42.9 |
| 15 | 8 | 1.75 | 0.50 | 1600 | 42.9 | 42.9 |

response and the fundamental information factors. Structure Expert programming, adaptation 7 is utilized to build up the trial plan for RSM. The information is broke down by utilizing a similar programming. Focal Composite Design (CCD) for three elements with three focus focuses is given in Table 3. Fifteen examinations are led by CCD and the exploratory perceptions are given in Table 4.

## 6. Results and Discussion

Investigations are planned and directed by utilizing RSM. The determination of proper model and the advancement of reaction surface models are completed by utilizing rendition 7 of the "Structure Expert programming". The exploratory information got utilizing the Central Composite Design (CCD) is used to build up the non-straight relapse model for the presentation attributes, viz., bearing internal ring surface temperature (T2) and bearing external ring surface temperature (T3) as spoke to by conditions (30) and (31) separately. Utilizing the exploratory information appeared in Table 4, reaction surface diagrams are created to research the impact of bearing framework parameters on different execution qualities.

### *(a) Inner ring surface temperature*

The response equation for Inner ring surface temperature in terms of the actual parameters is given as:

**Final Equation in Terms of Actual Factors:**

Bearing Inner ring surface temperature,

$$T_2 = 17.76019 + (13.55741 \times L) + (3.85 \times LP) + (7.86458E\text{-}003 \times S) - (2.26667 \times L \times LP) + (8.33333E\text{-}004 \times L \times S) + (1.75000E\text{-}003 \times LP \times S) - (3.72593 \times L^2) + 16.86667 \times LP^2 - (2.92318E\text{-}006 \times S^2) \quad \text{.... (30)}$$

The effect of various bearing parameters on bearing inner ring surface temperature is studied. Moreover, the surface plots of the response bearing inner ring surface temperature are

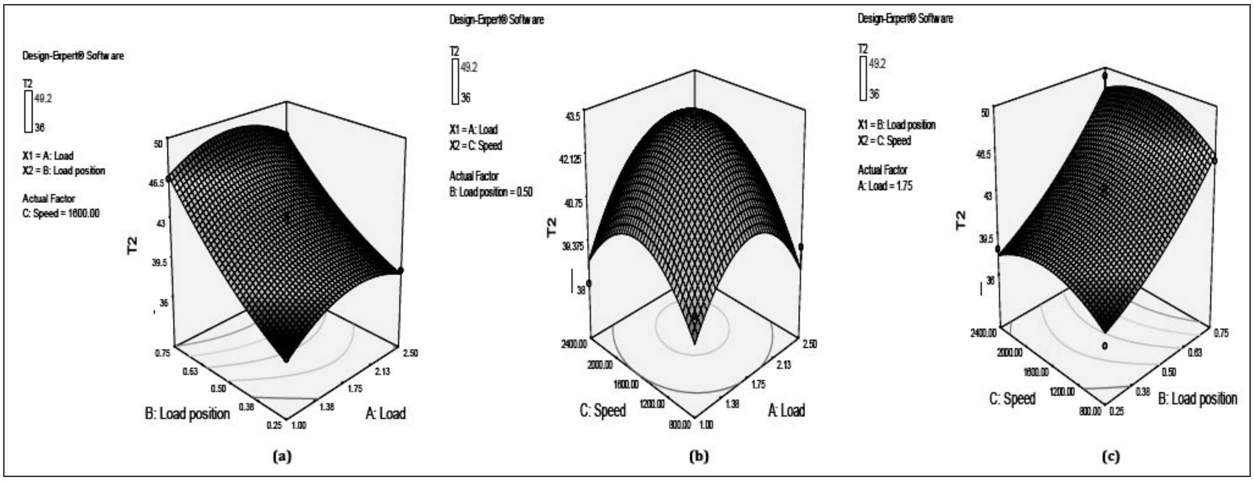


**Fig. 1.** Surface plots showing the variation of bearing inner ring surface temperature with respect to the combined effect of (a) L and LP (b) L and S (c) LP and S**.**

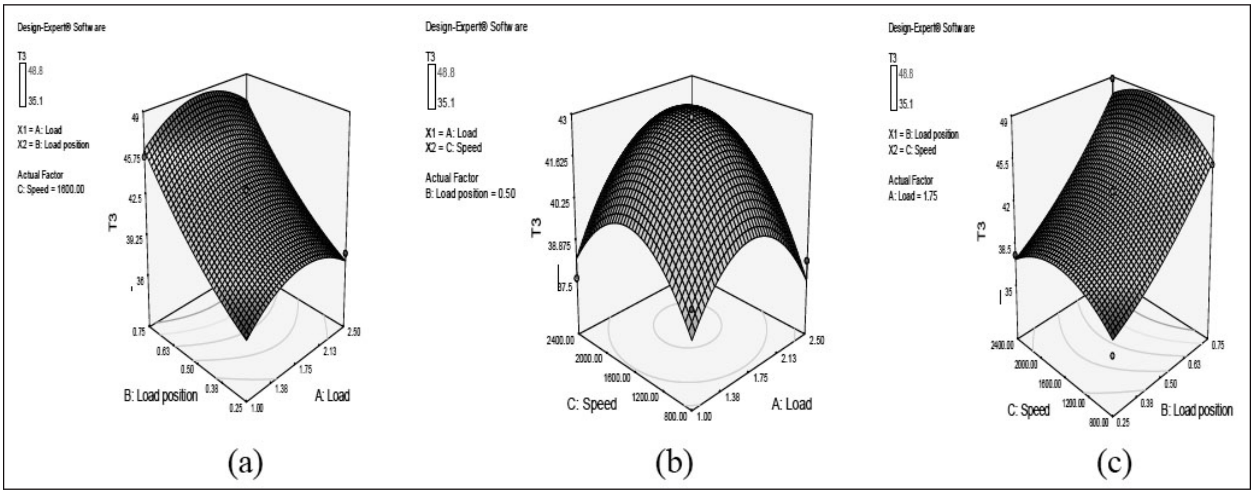


**Fig. 2.** Surface plots showing the variation of bearing outer ring surface temperature with respect to the combined effect of (a) L and LP (b) L and S (c) LP and S.

shown in Figure 1. From the surface plots, it can be observed that bearing inner ring surface temperature increased with an increase in load from 1 kg to 1.75 kg and then decreased with further increased load up to 2.5 kg. Bearing inner ring surface temperature increased with increase in load position from 0.25 m to 0.75 m. Bearing inner ring surface temperature increased with an increase in speed from 800 rpm to 1600 rpm and then decreased with further increased speed up to 2400 rpm, due to the the heat transfer process including conduction and within as well as in between the bearing elements.

### *(b) Outer ring surface temperature*

The response equation for outer ring surface temperature in terms of the actual parameters is given as:

**Final Equation in Terms of Actual Factors:**

Bearing Outer ring surface temperature,

$$T_3 = 17.15833 + (13.16667 \times L) + (2.16667 \times LP) + (9.5833E\text{-}003 \times S) - (0.26667 \times L \times LP) + (9.16667E\text{-}004 \times L \times S) + (1.5E\text{-}003 \times LP \times S) - (4.0 \times L^2) + (15.2 \times LP^2) - (3.43750E\text{-}006 \times S^2) \quad \text{.... } (\mathbf{31})$$

The effect of various bearing parameters on bearing outer ring surface temperature is studied. Moreover, the surface plots of the response bearing outer ring surface temperature are shown in Figure 2. From the surface plots, it can be observed that bearing outer ring surface temperature increased with an increase in load from 1 kg to 1.75 kg and then decreased with further increased load up to 2.5 kg. Bearing

**Table 5**
Analysis of variance for bearing inner ring surface temperature ($T_2$).

| Source of variation | DOF | Sum of Squares | Mean squares | F ratio | P value prob. > F |
|---|---|---|---|---|---|
| Model | 9 | 233.02 | 25.89 | 23.39 | 0.0014 |
| A-Load | 1 | 2.31 | 2.31 | 2.09 | 0.2081 |
| B-Load position | 1 | 191.10 | 191.10 | 172.66 | < 0.0001 |
| C-Speed | 1 | 3.64 | 3.64 | 3.29 | 0.1293 |
| AB | 1 | 0.72 | 0.72 | 0.65 | 0.4558 |
| AC | 1 | 1.00 | 1.00 | 0.90 | 0.3855 |
| BC | 1 | 0.49 | 0.49 | 0.44 | 0.5353 |
| $A^2$ | 1 | 16.22 | 16.22 | 14.65 | 0.0123 |
| $B^2$ | 1 | 4.10 | 4.10 | 3.71 | 0.1122 |
| $C^2$ | 1 | 12.92 | 12.92 | 11.68 | 0.0189 |
| Residual | 5 | 5.53 | 1.11 | | |
| Lack of Fit | 3 | 5.37 | 1.79 | 21.47 | 0.0448 |
| Pure Error | 2 | 0.17 | 0.083 | | |
| Total | 14 | 238.56 | | | |

**Table 6**
Analysis of variance for bearing outer ring surface temperature ($T_3$).

| Source of variation | DOF | Sum of Squares | Mean squares | F ratio | P value prob. > F |
|---|---|---|---|---|---|
| Model | 9 | 233.40 | 25.93 | 18.39 | 0.0025 |
| A-Load | 1 | 1.12 | 1.12 | 0.80 | 0.4127 |
| B-Load position | 1 | 186.24 | 186.24 | 132.09 | < 0.0001 |
| C-Speed | 1 | 4.50 | 4.50 | 3.19 | 0.1341 |
| AB | 1 | 1.000E-002 | 1.000E-002 | 7.092E-003 | 0.9362 |
| AC | 1 | 1.21 | 1.21 | 0.86 | 0.3968 |
| BC | 1 | 0.36 | 0.36 | 0.26 | 0.6348 |
| $A^2$ | 1 | 18.69 | 18.69 | 13.26 | 0.0149 |
| $B^2$ | 1 | 3.33 | 3.33 | 2.36 | 0.1848 |
| $C^2$ | 1 | 17.87 | 17.87 | 12.67 | 0.0162 |
| Residual | 5 | 7.05 | 1.41 | | |
| Lack of Fit | 3 | 7.05 | 2.35 | | |
| Pure Error | 2 | 0.000 | 0.000 | | |
| Total | 14 | 240.45 | | | |

outer ring surface temperature increased with increase in load position from 0.25 m to 0.75 m. Bearing outer ring surface temperature increased with an increase in speed from 800 rpm to 1600 rpm and then decreased with further increased speed up to 2400 rpm, due to the the heat transfer process including conduction, free convection and radiation within as well as in between the bearing elements. In the current study, the heat transfer due to radiation is neglected owing to low surface temperatures.

## 7. Test for Significance of the Regression Model

From the non-linear regression equations statistical validity of the models has been checked by conducting ANOVA test and by verifying the coefficient of correlation of the model. This test is performed by calculating the F-ratio, which is the ratio between the term mean square and residual mean square. The F-ratio, also called the variance ratio. This formula is used to measure the significance of the model under investigation for the variance of all the terms included in the error description at the desired level of significance. The ANOVA results for bearing inner ring surface temperature (T2) and bearing outer ring surface temperature (T3) are given in Tables 5 and 6. The results of ANOVA show that load position has significant contribution on the responses, such as T2 and T3 whereas load position has significant influence on cutting tool temperature with 95% confidence level. Further, the coefficient of correlation for T2 and T3 were found to be equal to 0.9768 and 0.9707 respectively. As coefficient of correlation lies close to 1 it provides an excellent relationship between the bearing parameters and the responses. 'P' value (Prob. > F) Ability to see the observed F value if the null hypothesis is true (there is no factor effect). Small probabilities call for rejection of the null hypothesis. The probability equals the proportion of the area under the curve of the F-distribution that lies beyond the observed F value.

The distribution of the F is determined by the degree of freedom associated with the variances being compared. The associated P value for the model was lower than 0.05 for all the responses indicates that the model is considered to be statistically significant. From Tables 5 and Table 6, values of "Prob > F" less than 0.05 indicate model terms are significant.

## 8. Conclusions

The experimental plan obtained by utilizing Central Composite Design (CCD) for Response Surface Methodology (RSM) in Radial ball bearing system using version 7.0 of Design-Expert software is presented in this paper. Surface plots are generated in order to examine the effect of process parameters on the performance characteristics. Non-linear regression models are developed in order establish relationship between responses and process parameters with 95% confidence level. The following conclusions are drawn:

- The results of ANOVA show Load position has significant influence on bearing inner ring surface temperature ($T_2$) and bearing outer ring surface temperature ($T_3$), whereas Rotational speed has significant influence on bearing temperature.
- The coefficient of correlation ($R^2$) for bearing inner ring surface temperature ($T_2$) and bearing outer ring surface temperature ($T_3$) is found to be 0.9768 and 0.9707 respectively which is close to 1 and indicates excellent relationship between performance characteristics and process parameters.
- For all the responses 'P' value (prob. >F) is less than 0.05 indicate that the model terms are significant.

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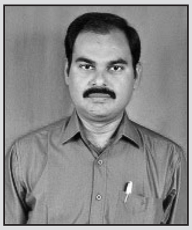

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