iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 14 Issue: VI Month of publication: June 2026

DOI: https://doi.org/10.22214/ijraset.2026.83834

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue VI June 2026- Available at www.ijraset.com

Thermo-Mechanical Failure Analysis and Reliability Enhancement of ID Fan Bearings Using CARB Technology

Sushil Sharma
[1]*Condition Monitoring- Manager, Technical Services Department, Hindalco Mahan Singrauli,486886, India*

Abstract: Induced Draft (ID) fans operating in alumina calciner units are exposed to severe thermal and mechanical loading conditions, leading to persistent reliability challenges in bearing systems. This study presents a detailed thermo-mechanical failure analysis of a non-drive end (NDE) bearing in an ID fan, where repeated failures of spherical roller bearings (SRB) were observed despite standard maintenance practices.

Field data revealed that the fan was operating at elevated flue gas temperatures of up to 195°C, significantly exceeding the OEM design limit, resulting in excessive shaft thermal expansion of up to 13.4 mm during transient conditions and 8.2 mm during steady-state operation.

The investigation established that the use of spherical roller bearings at both ends restricted axial displacement, leading to internal preload, lubrication film collapse, and progressive thermal runaway. This resulted in severe damage modes including cage fracture, roller skidding, spalling, and plastic deformation of raceways. Vibration analysis further confirmed high axial vibration, phase instability (10°–180° variation), and rotor dynamic imbalance under constrained conditions. To address these challenges, the study proposes the replacement of the spherical roller bearing with a CARB (toroidal roller bearing) at the NDE side.

The CARB bearing offers internal axial displacement capability (±10–15 mm) along with self-alignment, effectively decoupling thermal expansion and eliminating axial load transmission. Analytical evaluation indicates that this configuration significantly reduces bearing temperature, stabilizes vibration behaviour, and improves rotor dynamic performance.

The findings demonstrate that the primary cause of bearing failure was not load capacity limitation but the inability of conventional bearing arrangements to accommodate thermally induced axial displacement. The implementation of CARB bearing provides a robust and reliable solution for high-temperature industrial fans, leading to improved bearing life, reduced maintenance, and enhanced operational stability.

Keywords: CARB bearing, ID fan, thermal expansion, spherical roller bearing failure, axial load, rotor dynamics, phase instability.

I. INTRODUCTION

ID fans in calciner units handle high-temperature flue gases and are subjected to thermal gradients, misalignment, and structural distortion. Bearing failures in such systems are often attributed to inadequate consideration of axial expansion.

At Alumina plant, repeated failures of NDE bearings were observed despite proper maintenance practices. The failure mechanisms indicated:

- Thermal expansion-induced axial loading
- Lubrication film collapse
- Rotor instability and phase fluctuation

The conventional use of spherical roller bearings at both ends proved unsuitable under these operating conditions.

A. Spherical Roller Bearing

A rolling-element bearing that utilizes two rows of symmetrical, barrel-shaped (spherical) rollers operating on a common, curved outer ring raceway (figure-1).

figure-1: Spherical roller bearing

Self-Aligning: The curved outer raceway allows the inner ring and rollers to pivot or tilt. This easily accommodates shaft deflections and mounting errors without causing premature failure.
High Load Capacity: Designed to support exceptionally heavy radial loads and axial loads in both directions.
Robustness: Handles vibration and impact forces common in heavy industrial applications like mining crushers, vibrating screens, and wind turbines.

B. CARB Bearing

A patented, single-row toroidal roller bearing with long, slightly crowned rollers that combine the self-aligning features of a spherical bearing with the axial displacement features of a cylindrical roller bearing(figure-2).

figure-2: CARB bearing

Axial Displacement: Unlike traditional non-locating bearings that slide inside the housing (causing axial vibration and wear), a CARB bearing accommodates thermal shaft elongation internally through its uniquely curved rollers.
Load Capacity: Highly wear-resistant and capable of carrying massive radial loads.
Applications: Ideal for heavy-duty, high-heat applications where shafts expand significantly, such as paper mills, continuous casting machines, and industrial fans.

II. FIELD PROBLEM AND DESCRIPTION

Observed Fan inlet flue gas temperature high of 195°C against OEM limit of 147°C, due to which shaft high thermal expansion and resulting axial float higher side, Unstable phase observed (10°–180° variation), indicating rotor instability and abnormal operating condition. The bearing temperature was some higher.

Operating Condition

- Flue gas temperature: 195°C vs OEM limit 147°C
- Shaft length: 4300 mm
- Bearing type: SRB (22248 CC/C3 W33)

Observed Symptoms

- Bearing temperature: 90–95°C before trip
- Vibration spike: 9.5 mm/s (trip event)
- Phase instability: 10°–180° variation
- High axial vibration and looseness
- Cage fracture and roller displacement

III. OBSERVATIONS AND ANALYSIS

A. Thermal Expansion Analysis

Design condition:

- Shaft expansion: 6.5 mm

Actual condition:

- Startup expansion: 13.4 mm
- Running expansion: 8.2 mm

This expansion exceeded the allowable axial accommodation of SRB.

The failure followed a thermo-mechanical coupling sequence:

- Thermal expansion restriction
- Internal clearance elimination
- Axial preload generation
- Lubrication film collapse
- Metal-to-metal contact
- Thermal runaway (>220°C)
- Cage fracture and catastrophic failure

This all happened due to getting the evidence of Temper colours (>220 Deg C) (figure-3), Roller Spalling and Scoring (figure-4) and Plastic deformation of raceway (figure-5).

Figure-3: bearing color change due high temp.

Figure-4: Cage Fracture at Bearing NDE

Figure-5: Skidding at Rolling elements

- Vibration readings are attached for reference which shows axial vibration is on higher side (figure-6).
- During cross phase observations phase readings found unsteady (10° to 180° continuously varying) (figure-12).
- Minor bearing defects of outer race observed which is due to axial float restriction at Fan NDE side.
- Angular misalignment also observed at Fan side during cross phase analysis.
- Minor shaft runout also observed at impeller side.

RPM	915	905	905	915	915	915	905	905	905	905	905
Maximum Vibration	4.3	4.2	3.6	3.9	4.0	4.7	3.0	3.7	3.4	3.4	3.5
Inlet Temperature	190°	187°	187°	187°	187°	180°	187°	184°	184°	177°	188°
Fan DE Bearing Temp	67°	65°	64°	64°	65°	71°	69°	61°	59°	70°	69°
Fan NDE Bearing Temp	73°	69°	68°	68°	69°	72°	70°	65°	62°	72°	73°
MOTOR NDE	1.3	1.4	1.4	1.3	1.4	1.3	1.0	1.4	1.4	1.8	1.4
	0.2	0.5	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	0.8	1.0	0.9	0.9	1.0	0.9	0.7	1.0	0.9	1.2	1.0
	1.1	1.3	1.3	1.2	1.3	1.2	0.9	1.4	1.2	1.0	1.2
MOTOR DE	1.2	1.3	1.3	1.3	1.3	1.2	1.0	1.3	1.4	1.5	1.4
	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.2
	0.7	0.9	0.9	0.8	0.8	0.7	0.5	0.9	0.8	0.8	0.7
	1.9	1.5	1.6	1.9	2.4	1.5	1.3	1.9	1.8	1.5	1.8
FAN DE	2.3	2.6	2.6	2.5	2.4	2.3	1.7	2.8	2.8	2.7	2.5
	0.4	0.3	0.2	0.3	0.3	0.2	0.2	0.2	0.3	0.2	0.3
	1.6	1.6	1.8	1.6	1.6	1.6	1.2	1.7	1.5	1.6	1.7
	4.3	4.2	3.6	3.7	3.9	4.7	2.8	3.7	3.4	3.4	3.5
FAN NDE	2.1	2.1	1.9	2.1	1.6	2.0	1.9	2.3	2.7	2.2	2.6
	0.2	0.8	0.7	0.1	0.1	0.1	0.1	0.1	0.3	0.1	0.1
	0.8	1.0	0.4	0.6	0.7	0.8	0.3	0.9	0.8	0.9	0.5
	3.2	3.8	2.9	3.9	4.0	3.5	3.0	3.5	2.5	3.1	3.0

Figure-6: Vibration field readings

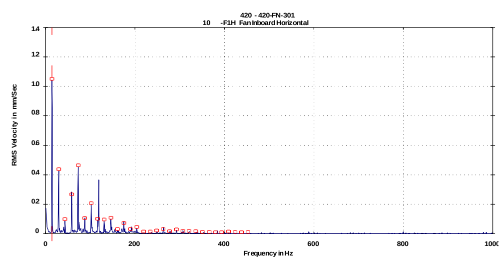


figure-7: Vibration signature FDE side(H)

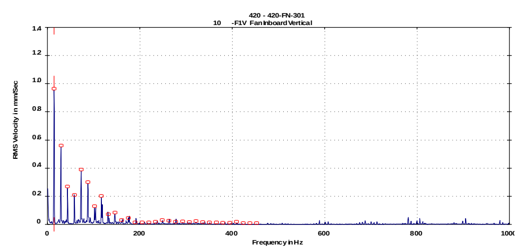


figure-7: Vibration signature FDE side(V)

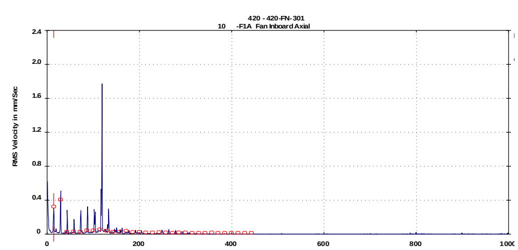


figure-8: Vibration signature FDE side(A)

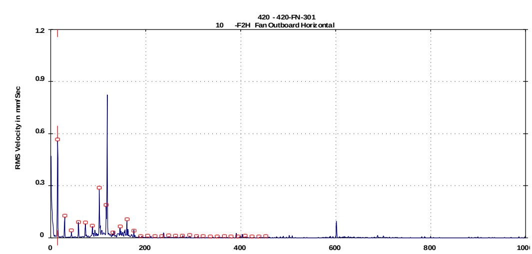


figure-9: Vibration signature FNDE side(H)

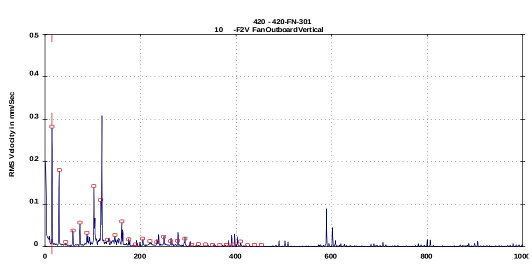


figure-10: Vibration signature FNDE side(V)

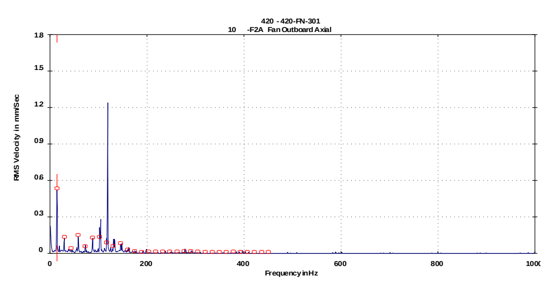


figure-11: Vibration signature FNDE side(A)

Cross Phase Readings					
RPM-885					
Across the Coupling		F-DE		F-NDE	
Direction	Angle	Direction	Angle	Direction	Angle
H-H	160°	H-V	92°	H-V	110° (Not Stable)
V-V	85°	H-A	80°(Not Stable)		
A-A	172°				
		Foundation		Foundation	
		H-H	60°	H-H	15°

Figure-12: Cross Phase vibration analysis

FFT analysis shows a dominant frequency at 123 Hz at both fan bearings
Axial vibration is high at both DE and NDE bearings.
Minor bearing outer race defects are indicated at the Fan-NDE bearing which is due to high axial float and its restriction at Fan NDE floating side.
Minor mechanical looseness is also observed at the fan bearings.
Axial phase readings are inconsistent, and significant phase variations are observed.

B. Shaft Thermal Expansion Calculation

$\Delta L=\alpha\times L\times\Delta T$,
As per design:
α = Coefficient of thermal expansion (for Steel 12×10^{-6} /°C),
Assume L = 4300mm (Shaft length between bearings (mm)), ΔT = (162-36) °C,
Inside flue gas temp=162 °C (average), Ambient temp-36 Deg C
$\Delta L= 12 \times 10^{-6}$ X 4300 X126 = 6.5 mm
So total shaft growth=6.5 mm

As per Actual (during startup):
ΔL = Axial expansion (mm), α = Coefficient of thermal expansion (for Steel 12×10^{-6} /°C),
Assume L = 4300mm (assume)Shaft length between bearings (mm), ΔT = (295-36) °C,
Inside flue gas temp=295 °C , Ambient temp-36 Deg C
SO axial expansion = 12×10^{-6} X 4300 X259 = 13.4 mm (Maximum)
So total shaft growth= 13.4 mm.
In unit startup time this total shaft growth is very high 13.4 mm which creates very high axial thrust and float and this will be very harmful for bearing and its components.

As per Actual (Normal in running):
ΔL = Axial expansion (mm), α = Coefficient of thermal expansion (for Steel 12×10^{-6} /°C),
Assume L = 4300mm Shaft length between bearings (mm), ΔT = (195-36) °C,
Inside flue gas temp=195 °C , Ambient temp-36 Deg C
SO axial expansion = 12×10^{-6} X 4300 X159 = 8.2 mm (average)
So total shaft growth= 8.2 mm.
So if we use spherical roller bearings at both ends so this 8.2 mm is restricted, so it leads to Axial load on both bearings, Internal preload, Heat generation and Phase instability.

C. Solution for Existing configuration and Problem

Current Bearing
Type: 22248 CC/C3 W33 (Spherical Roller Bearing) at Fan NDE side location
Its function is for Radial + Axial load carrying so due to very high operating temperature 195 °C there is significant shaft thermal expansion and high axial vibration also phase is shifting 180 °C and it is unsteady so it indicates that angular misalignment is there

and also high axial float observed which is restricting at FNDE side due to this high temperature at bearing and phase instability means internal looseness observed.
During vibration spectrum analysis bearing internal looseness is observed.
Spherical roller bearing takes both radial and axial load at this high temperature Axial expansion induces additional thrust load and bearing experiences internal stress and friction, which results Heat generation increases, Lubrication film collapses, Bearing life reduces and Phase instability increases.

D. Proposed Bearing CARB (C3048)

CARB Bearing Axial Displacement Capability
CARB allows free axial movement inside bearing so No axial load transmitted and Typical bears displacement ±10–15 mm so it eliminates thermal expansion stress completely.
Misalignment Compensation
CARB can tolerate angular misalignment similar to SRB , Improves stability under thermal distortion
Minimizes Heat Generation
Pure radial load bearing causes less friction and No axial thrust loading causes lower temperature.
Improves Rotor Stability
CARB removes axial constraint so rotor finds its natural center and Phase becomes stable, so CARB stabilize rotor dynamics.

Parameter	**SRB**	**CARB**
Axial load	High	Eliminated
Temperature	90–95°C	Reduced
Vibration	Unstable	Stable
Bearing life	<1 year	>2 years expected
Rotor stability	Poor	Improved

figure-13: Spherical roller bearing Vs CARB performance

CARB bearing enables Natural shaft centering(figure-14).
It Reduced dynamic instability.
There is elimination of phase fluctuation in CARB.

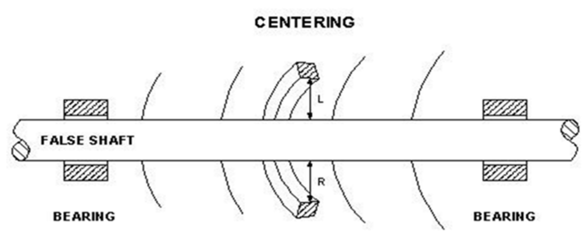


Figure-14: Natural shaft centering

.

IV. CONCLUSIONS

This study presents a comprehensive thermo-mechanical failure analysis of an ID fan bearing system operating under high-temperature conditions in an alumina calciner environment. The investigation clearly establishes that excessive shaft thermal expansion, reaching up to 13.4 mm during transient conditions and 8.2 mm in steady-state operation, was the primary driving factor behind repeated bearing failures. The use of spherical roller bearings at both the drive and non-drive ends resulted in axial constraint, leading to internal preload, lubrication film collapse, and progressive thermal deterioration.
The failure mechanism followed a well-defined sequence involving expansion restriction, clearance elimination, metal-to-metal contact, and thermal runaway, ultimately resulting in severe damage such as cage fracture, roller skidding, spalling, and raceway deformation. Vibration signatures further validated the presence of axial instability and rotor dynamic imbalance, evidenced by high axial vibration levels and continuous phase fluctuation.
The study demonstrates that conventional spherical roller bearing arrangements are fundamentally unsuitable for applications involving large thermal growth, as they cannot effectively decouple axial displacement from radial load support. In contrast, the proposed implementation of a CARB bearing at the NDE side provides a robust engineering solution by enabling internal axial displacement while maintaining high radial load capacity and self-alignment capability.

By eliminating axial load transmission, the CARB bearing stabilizes rotor dynamics, reduces bearing operating temperature, minimizes frictional losses, and significantly enhances bearing life and reliability. The findings reveal that the root cause of failure lies not in load capacity limitations but in the inability of the bearing system to accommodate thermally induced axial movement.

This research highlights the critical importance of proper bearing selection based on thermo-mechanical operating conditions and provides a practical, field-validated solution for reliability improvement in high-temperature rotating equipment. The adoption of CARB bearings in similar industrial fan applications can lead to improved operational stability, reduced maintenance interventions, and optimized lifecycle performance.

V. ACKNOWLEDGE

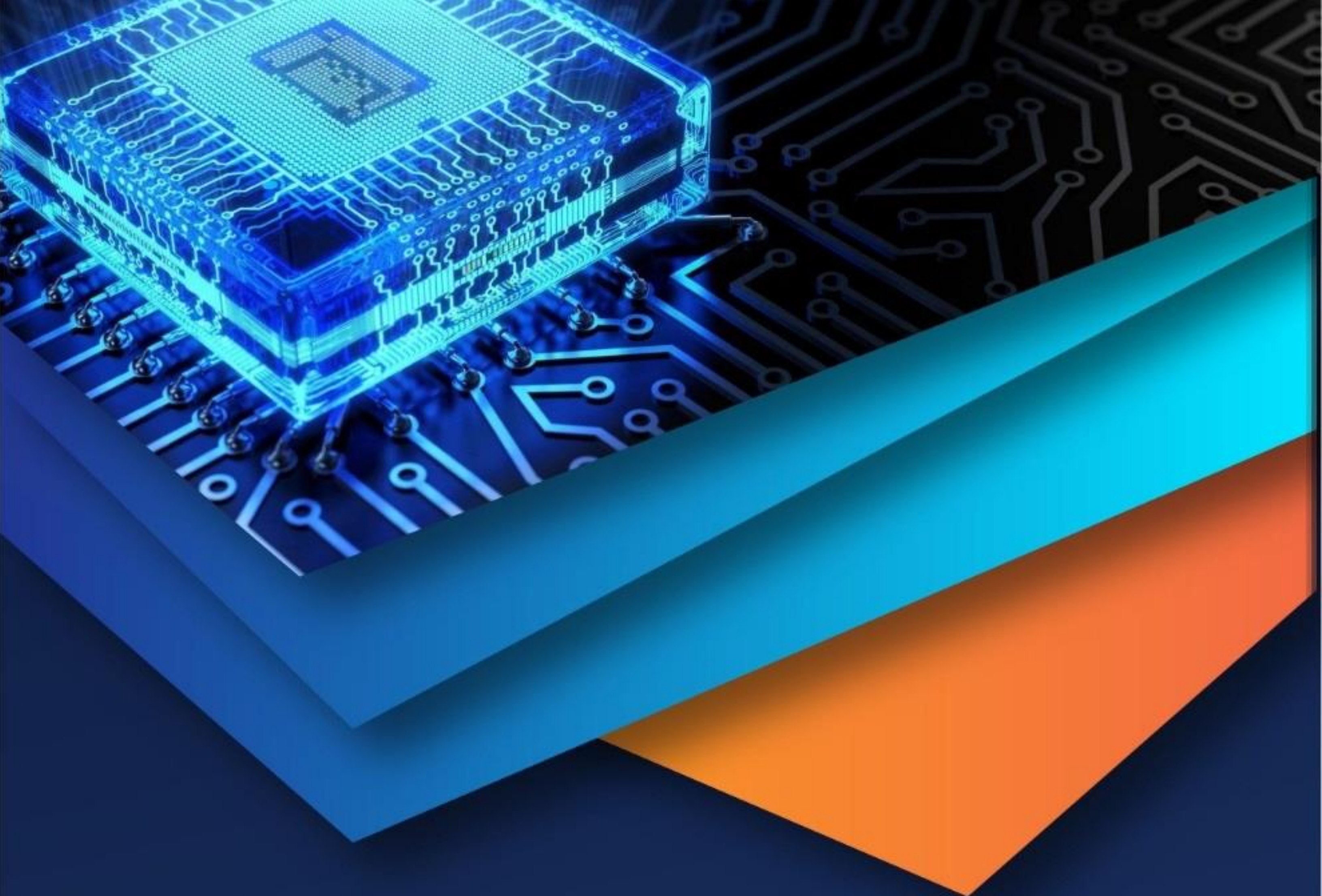
I would like to express my sincere gratitude to my mentor Mr. Atish Mondal (Head Reliability- MCOE), whose expert guidance, encouragement, and insightful feedback were invaluable at every stage of this work.

Special appreciation goes to my colleagues and peers for their constant support, lively discussions, and collaborative spirit, which greatly enriched this study.

Finally, I am profoundly thankful to my family and friends for their patience, understanding, and unwavering encouragement throughout this research.

REFERENCES

[1] SKF bearing catalogue hand book.
[2] FAG and NTN bearing catalogue and literature.
[3] Mobius VCAT-III vibration analysis literature.
[4] Advancement Vibration Analysis/ Mechanalysis literature.
[5] Vibration standards ISO10816 and ISO7919, ISO 20816-3:2022.



10.22214/IJRASET

INDEX COPERNICUS

45.98

IMPACT FACTOR: 7.129

TOGETHER WE REACH THE GOAL

IMPACT FACTOR: 7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY