UNIVERSITY GRANTS COMMISSION
BAHADURSHAH ZAFAR MARG
NEW DELHI-110002

F No - 43-299/2014(SR)

Dated :- August, 2015

2⁹

MRP-MAJOR-ELEC-2013-27085
(GENERAL)

29 DEC 2015

The Under Secretary (FDIII),
University Grants Commission,
Bahadur Shah Zafar Marg,
New Delhi-110002

Sub - Release of Grants-in-aid to **Shivaji University, Kolhapur, Vidyanagar, Kolhapur, Maharashtra Pin No. 416004** for the year 2015-16 under Plan in respect of Major Research Project entitled **"Studies on Fuzzy Logic Thermal Compensation Technique for High Speed Precision Machine** " awarded to **Dr. MUDHOLKAR RAVINDRA RAMCHANDRA , Department of Electronics** , Tenure of project for 3 year(s) w e f **01/07/2015**.

Sir/Madam,

I am directed to convey the approval sanction of the University Grants Commision for payment of grant of **Rs. 5,99,000/-** (Rupees **FIVE LAKHS NINETY NINE THOUSAND ONLY**) as **1st instalment** for the years **2015-16** towards Major Research Project to the **FINANCE & ACCOUNTS OFFICER , Shivaji University, Kolhapur, Vidyanagar, Kolhapur, Maharashtra Pin No. 416004** for the Plan expenditure to be incurred during 2015-16

S. No.	Items	Head of Account	Amount Approved(Rs.)	Grant being Released as 1st Installment(Rs.)	Grant Already Released(Rs.)	Total Grant(Rs.)
A.	**Non-Recurring**					
1	Books & Journals	3(A).49(a).35	Rs. 0/-	Rs. 0/-	-	Rs. 0/-
2	Equipment		Rs. 1,70,000/-	Rs. 1,70,000/-	-	Rs. 1,70,000/-
B.	**Recurring**					
1	Honorium to Retd. Teacher @ Rs. 18,000/- p m.		Rs. 0/-	Rs. 0/-	-	Rs. 0/-
2	a. Project Fellow (Non-Gate/Non NET) @ Rs. 14,000/- p m / b. Project Fellow (Gate/NET/GPAT) @ Rs 16,000/- p m. Tenure - 3 year(s)		Rs. 6,00,000/-	Rs. 3,00,000/-	-	Rs. 3,00,000/-
3	Chemical/Glassware/Consumable (Raw Material & Packaging Material etc.)	3(A).49(a).31	Rs. 0/-	Rs. 0/-		Rs. 0/-
4.	Contingency		Rs. 90,000/-	Rs. 45,000/-	-	Rs. 45,000/-
5.	Hiring Services		Rs. 0/-	Rs. 0/-	-	Rs. 0/-
6.	Travel / Field Work		Rs. 30,000/-	Rs. 15,000/-	-	Rs. 15,000/-
7.	Any Other		Rs. 0/-	Rs. 0/-		Rs. 0/-
8.	Overhead Charges 10% of approved recurring Grant (Except Travel & Field Work)		Rs. 69,000/-	Rs. 69,000/-	-	Rs. 69,000/-
	Total (A + B)		Rs. 9,59,000/-	Rs. 5,99,000/-		Rs. 5,99,000/-

The sanctioned amount is debitable to the Major Head 3(A).49(a).31 Rs. 4,29,000/- & Head 3(A).49(a).35 Rs. 1,70,000/- and is valid for payment during financial year 2015-16 .

The amount of the Grant shall be drawn by the Under Secretary (Drawing and Distributing Officer), University Grants Commission on the Grants-in-aid Bill and shall be disbursed to and credited to the FINANCE & ACCOUNTS OFFICER , Shivaji University, Kolhapur, Vidyanagar, Kolhapur, Maharashtra Pin No. 416004 through Electronic mode as per the following details.

	Payment Details	
(a)	Bank Name & Address of Branch	UCO Bank, Vidyanagar Branch, Kolhapur
(b)	Account No.	02890200000001
(c)	Type of Account (SB/Current/Cash Credit)	CURRENT
(d)	IFSC Code	UCBA 000 0289
(e)	MICR Code of Branch	416028003
(f)	Whether Bank Branch is RTGS or NEFT enabled? :	Yes (RTGS/NEFT/Both)
(g)	Name & Address of Account Holder	Finance & Accounts Officer, Shivaji University, Kolhapur

The Grant is subject to the adjustment of the basis of Utilization Certificate in the prescribed performa submitted by the University/Colleges/Institution.

The University/College/Institution shall maintain proper accounts of the expenditure out of the grants which shall be utilized only on approved items of expenditure.

The University/Institution may follow the General Financial Rules, 2005 and take Urgent necessary action to amend their manuals of financial procedures to bring them in conformity with GFRs, 2005 and those don't have their own approved manuals on financial procedures may adopt the provisions of GFR's 2005 and instructions/guideline there under from time to time.

The Utilization Certificate to the effect that the grant has been utilized for the purpose for which it has been sanctioned shall be furnished to the University Grants Commission as early as possible after the close of the current financial year.

The assets acquired wholly or substantially out of University Grant Commission's grant shall not be disposed or encumbered of utilized for the purposes other than those for which the grant was given, without proper sanctioned of the University Grants Commission and should, at any time the College/University ceased in function such assets shall revert to the University Grants Commission.

A register of assets acquired wholly or substantially out of the grant shall be maintained by the University/College in the prescribed proforma.

The grantee institution shall ensure the utilization of grant-in-aid for which it is being sanction/paid. In case non-utilization/part utilization, thereof simple interest @ 10% per annum as amended from time to time on unutilized amount from the date of drawl to the date of refund as per provisions contained in General Financial Rules of Govt. of India will be charged.

The University/College/Institute shall follow strictly the Government of India / University Grants Commission guidelines regarding implementation of the reservation policy [both vertical (for SC, ST & OBC) and horizontal (for persons with disability etc.)] in teaching and non-teaching posts.

The University/College shall fully implement the Official Language Policy of Union Govt. and comply with the Official Language Act, 1963 and Official Languages (Use for Official purposes of the Union) Rules, 1976 etc.

The sanction is issued in exercise of the delegation of powers vide University Grants Commission Office Order No. 69/2014 F.No.10-11/12 (Adma. IA & B) dated 26/03/2014 .

The University/Institution shall strictly follow the University Grants Commission Regulations on curbing the menace of Ragging in Higher Educational Institutions, 2009.

The University/Institution shall take immediate action for its accreditation by National Assessment & Accreditation Council (NAAC)

The accounts of the University/Institution will be open for audit by the Comptroller & Auditor General of India in accordance with the provisions of General Financial Rules, 2005.

The annual accounts i.e. balance sheet, income and expenditure statement and statement of receipts and payments are to be prepared strictly in accordance with the Uniform Format of Accounting prescribed by Government.

The funds to the extent of Rs. _____ Crores are available under the scheme or BE/RE of the yea 2015-16.

This issue with the concurrence of IFD Vide No. Diary No. **10946** Dated, **10.03.2015**.

This issue with the approval of the **Chairman, (UGC)** Vide Diary No. **28731** Dated **30.04.2015**.

Yours faithfully

(G.S AULAKH
Under Secretar

Copy forwarded for information and necessary action to :-

1. The **FINANCE & ACCOUNTS OFFICER**, Shivaji University Kolhapur - 416004 (MS)
2. Office of the Director General of Audit, Central Revenues, A.G.C.R. Building, I.P. Estate, New Delhi.
3. Accountant General, Govt. of State, **Maharashtra**.
4. Dr. Dr. **MUDHOLKAR RAVINDRA RAMCHANDRA**, Principal Investigator, **Department of Electronics** Shivaji University, Kolhapur, Vidyanagar, Kolhapur, Maharashtra Pin No. 416004.
5. The **Principal**, Shivaji University, Kolhapur, Vidyanagar, Kolhapur, Maharashtra Pin No. 416004

Registrar

(ARUN KUMAR SINHA
SECTION OFFICEI

SHIVAJI UNIVERSITY, KOLHAPUR

SU/C. & U. D. Section/VUS/ 985

DATE : 1 4 JAN 2016

Copy f.w.c's for information & necessary action to :

1. The Head, Department of Electronics.
2. Dr. R. R. Mudholkar, P. I., Department of Electronics.
3. A/C (P.G. Bills) Section.
4. A/C (Cash Book) Section.
5. Budget Section. (Please open new budget head)
6. Statistical Officer, Stat Cell.
7. Est. P. G.

Dy. Registrar

- 4 JAN 2016

Supdt.   Director
Registrar   Register\ B.C.U.D

UNIVERSITY GRANTS COMMISSION
BAHADUR SHAH ZAFAR MARG
NEW DELHI – 110 002

STATEMENT OF EXPENDITURE IN RESPECT OF MAJOR RESEARCH PROJECT

1. Name of Principal Investigator   : Dr. Mudholkar Ravindra Ramchandra

2. Department of Principal Investigator   : Department of Electronics

   University/College   : Shivaji University, Kolhapur

3. UGC approval Letter No. and Date   : F.No.-43-299/2014(SR) dated 29 December 2015

4. Title of the Research Project   :Studies on Fuzzy Logic Thermal Compensation

                                      Technique for High Speed Precision Machine

5. Effective date of starting the project   :01/07/2015

6. a. Period of Expenditure : From   : 01/07/2015 to 30/06/2018

   b. Details of Expenditure

Sr. No.	Item	Amount Approved (Rs.)	Grant being Released as 1st Installment (Rs.)	Expenditure Incurred (01/07/2015 to 31/03/2016) (Rs.)	Expenditure Incurred (01/04/2016 to 31/03/2017) (Rs.)	Expenditure Incurred (01/04/2017 to 31/03/2018) (Rs.)	Expenditure Incurred (01/04/2018 to 30/06/2018) (Rs.)	Total Expenditure (01/07/2015 to 30/06/2018) (Rs.)	Balance (Rs.)
A	**Non-Recurring**								
1	Books & Journals	Rs. 0/-	Rs. 0/-	-	-	-	-	-	-
II	Equipment	Rs.1,70,000/-	Rs. 1,70,000/-	Nil	Rs. 77,187/-	Rs. 12,802/-	Nil	Rs. 89,989/-	Rs.80,011/-
B	**Recurring**								
1	Honorium to Rent Teacher	Rs. 0/-	Rs. 0/-	-	-	-	-	-	-
II	Project Fellow	Rs.6,00,00 0/-	Rs.3,00,000/-	Nil	Rs.1,36,774/-	Rs.1,12,000/-	Nil	Rs.2,48,774/-	Rs.51,226/-
III	Chemicals and Glassware	Rs. 0/-	Rs. 0/-	-	-	-	-	-	-
IV	Contingency	Rs. 90,000/-	Rs. 45,000/-	Nil	Rs. 14,578/-	Rs. 4,209/-	Nil	Rs. 18,787/-	Rs. 26,213/-
V	Hiring Services	Rs. 0/-	Rs. 0/-	-	-	-	-	-	-
VI	Travel / Field Work	Rs.30,000/-	Rs. 15,000/-	Nil	Rs. 13,374/-	Nil	Nil	Rs. 13,374/-	Rs. 1,626/-
VII	Any other	Rs. 0/-	Rs. 0/-	-	-	-	-	-	-
VIII	Overhead Charges	Rs. 69,000/-	Rs. 69,000/-	Nil	Rs. 34,500/-	Rs. 34,500/-	Nil	Rs. 69,000/-	Rs. 0/-
	Total	Rs.9,59,000/-	**Rs.5,99,000/-**	Nil	Rs. 2,76,413/-	Rs.1,63,511/-	Nil	**Rs.4,39,924/-**	**Rs.1,59,076/-**

c. Staff (Project Fellow)

Date of Appointment: 15/07/2016

S. No	Items	Amount Approved (Rs.)	Grant being Released as 1st Installment (Rs.)	From	To	Expenditure incurred (Rs.)	Balance (Rs.)
1	Honorarium to PI (Retired Teachers) @ Rs. 18,000/-p.m.	-	-	-	-	-	-
2	Project fellow: i) NET/GATE qualified-Rs. 16,000/- p.m. for initial 2 years and Rs. 18,000/- p.m. for the third year. ii) Non-GATE/Non-NET-Rs. 14,000/- p.m. for initial 2 years and Rs. 16,000/- p.m. for the third year.	Rs.6,00,000/-	Rs.3,00,000/-	15/07/2016	31/03/2017	Rs.1,36,774/-	Rs.1,63,226/-
				01/04/2017	31/03/2018	Rs.1,12,000/-	Rs.51,226/-
				01/04/2018	30/06/2018	Nil	Nil
	Total	Rs.6,00,000/-	Rs.3,00,000/-	-	-	Rs.2,48,774/-	Rs.51,226/-

1. It is certified that the appointment have been made in accordance with the terms and conditions laid down by the Commission.
2. If as a result of check or audit objection some irregularly is noticed at later date, action will be taken to refund, adjust or regularize the objected amounts.
3. Payment @ revised rates shall be made with arrears on the availability of additional funds.
4. Certified that the grant of Rs. 9,59,000/- (Rupees Nine Lakh Fifty Nine Thousand Only) has been sanctioned from the University Grants Commission under the scheme of support for Major Research Project entitled **Studies on Fuzzy Logic Thermal Compensation Technique for High Speed Precision Machine** vide UGC letter No. **F.43-299/2014(SR)** dated **29 December 2015**. An amount of **Rs. 5,99,000/-** (Rupees Five Lakh Ninety Nine Thousand Only) has been received as first installment. An amount of **Rs 4,39,924 (Rupees Four Lakh Thirty Nine Thousand Nine Hundred Twenty Four Only)** has been utilized for the purpose for which it was sanctioned and in accordance with the terms and conditions laid down by the University Grants Commission.

SIGNATURE OF THE
PRINCIPAL INVESTIGATOR

Dr. R. R. Mudholkar
Principal Investigator
UGC Major Research Project

REGISTRAR
Registrar
Shivaji University, Kolhapur.

For Sankpal Kulkarni & Associates
Chartered Accountants
STATUORY AUDITOR

Amit D. Patil
Partner-M-No. 126102

UNIVERSITY GRANTS COMMISSION
BAHADUR SHAH ZAFAR MARG
NEW DELHI – 110 002

STATEMENT OF EXPENDITURE INCURRED ON TRAVEL/FIELD WORK

Name of the Principal Investigator: Dr. Ravindra Ramchandra Mudholkar.

Name of the Place visited	Duration of the Visit		Mode of Journey	Expenditure Incurred (Rs.)	Balance (Rs.)
	From	To			
UGC Office at Bahadurshah, Zafar Marg, New Delhi	26/02/2017	01/03/2017	Public Transport and Air Transport	Rs.13,374/-	Rs.1,626/-
	01/04/2017	31/03/2018	-	-	Rs.1,626/-
	01/04/2018	30/06/2018	-	-	Rs.1,626/-

Certified that the above expenditure is in accordance with the UGC norms for Major Research Projects

SIGNATURE OF THE
PRINCIPAL INVESTIGATOR
Dr. R. R. Mudholkar
Principal Investigator
UGC Major Research Project

REGISTRAR
Registrar
Shivaji University, Kolhapur.

For Sankpal Kulkarni & Associates
Chartered Accountants
STATUTORY AUDITOR

Amit D. Patil
Partner-M-No. 126102

UNIVERSITY GRANTS COMMISSION
BAHADUR SHAH ZAFAR MARG
NEW DELHI – 110 002

Utilization Certificate

Certified that the grant of Rs. **9,59,000/- (Rupees Nine Lakh Fifty Nine Thousand Only)** has been sanctioned from the University Grants Commission under the scheme of support for Major Research Project entitled **Studies on Fuzzy Logic Thermal Compensation Technique for High Speed Precision Machine** vide UGC letter No. **F.43-299/2014(SR)** dated **29 December 2015**. An amount of **Rs. 5,99,000/- (Rupees Five Lakh Ninety Nine Thousand Only)** has been received as first installment. An amount of **Rs 4,39,924 (Rupees Four Lakh Thirty Nine Thousand Nine Hundred Twenty Four Only)** has been utilized for the purpose for which it was sanctioned and in accordance with the terms and conditions laid down by the University Grants Commission.

For Sankpal Kulkarni & Associates
Chartered Accountants

A. Patil
Amit D. Patil
Partner-M-No. 126102

SIGNATURE OF THE PRINCIPAL INVESTIGATOR
Dr. R. R. Mudholkar
Principal Investigator
UGC Major Research Project

REGISTRAR
Registrar
Shivaji University, Kolhapur

STATUTORY AUDITOR
करबुक विभाग दि॰ 31-7-2018
उपरोक्त D.I.P.249 Studies on fuzzy... या

शिर्षिकाखाली उपयोगिता प्रमाणपत्रामध्ये नमूद केलेल्या जमा खर्चाची नोंदी कॅशबुकसोबत तपासल्या असता त्या बरोबर दिसून येतात. सदर शिर्षकास दि. 30-6-2018 रोजी रू. 1,59,076/- इतका credit balance (शिल्लक जमा) दिसून येतो.

31-7-2018

31/7/18
अधीक्षक

PROFORMA FOR SUPPLYING THE INFORMATION IN
RESPECT OF THE STAFF APPOINTED UNDER THE
SCHEME OF MAJOR RESERCH PROJECT

UGC FILE NO.F: 43-299/2014(SR) (HRP) YEAR OF COMMENCEMENT: 01/07/2015
: 22/04/2016 (Grant Received)

NAME OF THE PROJECT: **Studies on Fuzzy Logic Thermal Compensation**
Technique for High Speed Precision Machine

1.	Name of the Principal Investigator	Dr. Mudholkar Ravindra Ramchandra				
2.	Name of the University	Shivaji University, Kolhapur				
3.	Name of the Research Personnel Appointed	Ms. Patil Poonam Siddu				
4.	Academic Qualification	Sr. No.	Qualification	Year	Marks	%age
		1	M.Sc	2009	1933 out of 2400	80.54%
		2	NET	2013	------	-----
		3	SET	2014	------	-------
5.	Date of Joining	15/07/2016				
6.	Date of Birth of Research Personnel	16/11/1986				
7.	Amount of HRA, if, drawn	Nil				
8.	Number of Candidate applied for the post	06				

CERTIFICATE

This is to certify that all rules and regulations of UGC Major Research Project outlined in the guidelines have been followed. Any lapse on the part of the University will liable to terminate of said UGC Project

Principal Investigator
Dr. R. R. Mudholkar
Principal Investigator
UGC Major Research Project

Head of the Department
Head
Department of Electronics
Shivaji University,
Kolhapur-416 004

Registrar
Registrar
Shivaji University, Kolhapur

UNIVERSITY GRANTS COMMISSION
BAHADUR SHAH ZAFAR MARG
NEW DELHI – 110 002
MAJOR RESEARCH PROJECT COPY OF THE SPECIMEN OF HOUSE RENT
FOR PROJECT FELLOW

Certified that **Ms. Poonam Siddu Patil** is **not paying** House Rent and is **not eligible** to draw House Rent Allowances as per University Rules.

Registrar
(Signature with Seal)
Registrar
Shivaji University, Kolhapur.

Certified that. **Ms. Poonam Siddu Patil** staying independently and therefore is **not eligible** to draw House Rent p.m. minimum admissible to a Lecturer as per University Rules.

Registrar
(Signature with Seal)
Registrar
Shivaji University, Kolhapur.

Certified that Shri/Dr. ……. been provided accommodation in the Hostel. But he/she could not be provided with single seated flat type accommodation as recommended by the Commission, Hostel fee @Rs …….. per month w.e.f. is being charged from him/her.

Registrar
(Signature with Seal
Registrar
Shivaji University, Kolhapur.

UNIVERSITY GRANTS COMMISSION
BAHADUR SHAH ZAFAR MARG
NEW DELHI – 110 002

STATEMENT OF EXPENDITURE INCURRED TOWARDS SALARY & HRA of PROJECT FELLOW

Date of appointment of Project Fellow: 15/07/2016

S. No	Items	From	To	Amount Approved (Rs.)	Grant being Released as 1st Installment (Rs.)	Expenditure incurred (Rs.)	Balance
1	Honorarium to PI (Retired Teachers) @ Rs. 18,000/-p.m.	-	-	-	-	-	-
2	**Project fellow:** **i) NET/GATE qualified-**Rs. 16,000/- p.m. for initial 2 years and Rs. 18,000/- p.m. for the third year. **ii) Non-GATE/Non-NET-** Rs. 14,000/- p.m. for initial 2 years and Rs. 16,000/- p.m. for the third year.	15/07/2016	31/07/2016	Rs.6,00,000/-	Rs.3,00,000/-	Rs. 8,774/-	Rs.2,91,226/-
		01/08/2016	31/08/2016			Rs.16,000/-	Rs.2,75,226/-
		01/09/2016	30/09/2016			Rs.16,000/-	Rs.2,59,226/-
		01/10/2016	31/10/2016			Rs.16,000/-	Rs.2,43,226/-
		01/11/2016	30/11/2016			Rs.16,000/-	Rs.2,27,226/-
		01/12/2016	31/12/2016			Rs.16,000/-	Rs.2,11,226/-
		01/01/2017	31/01/2017			Rs.16,000/-	Rs.1,95,226/-
		01/02/2017	28/02/2017			Rs.16,000/-	Rs.1,79,226/-
		01/03/2017	31/03/2017			Rs.16,000/-	Rs.1,63,226/-
		01/04/2017	30/04/2017			Rs.16,000/-	Rs.1,47,226/-
		01/05/2017	31/05/2017			Rs.16,000/-	Rs.1,31,226/-
		01/06/2017	30/06/2017			Rs.16,000/-	Rs.1,15,226/-
		01/07/2017	31/07/2017			Rs.16,000/-	Rs.99,226/-
		01/08/2017	31/08/2017			Rs.16,000/-	Rs.83,226/-
		01/09/2017	30/09/2017			Rs.16,000/-	Rs.67,226/-
		01/10/2017	31/10/2017			Rs.16,000/-	Rs.51,226/-
	Total:			Rs.6,00,000/-	Rs.3,00,000/-	Rs.2,48,774/-	Rs.51,226/-

Certified that the above expenditure is in accordance with the UGC norms for Major Research Projects

SIGNATURE OF THE
PRINCIPAL INVESTIGATOR
Dr. R. R. Mudholkar
Principal Investigator
UGC Major Research Project

REGISTRAR
Registrar
Shivaji University, Kolhapur

For Sankpal Kulkarni & Associates
Chartered Accountants
STATUTORY AUDITOR
A. Patil
Amit D. Patil
Partner-M-No. 126102

UNIVERSITY GRANTS COMMISSION
BAHADUR SHAH ZAFAR MARG
NEW DELHI – 110 002.

Final Report of the work done on the Major Research Project.

1. Project report No. 1st/2nd/3rd/ Final   **:** Final

2. UGC Reference No.   **:** F.No.-43-299/2014 (SR)

3. Period of report: from   **:** 01/07/2015 to 30/06/2018

4. Title of research project   **:** Studies on Fuzzy Logic Thermal Compensation Technique for High Speed Precision Machine.

5. a) Name of the Principal Investigator   **:** Dr. Mudholkar Ravindra Ramchandra

   b) Deptt.   **:** Department of Electronics

   c) University/College where work has progressed   **:** Shivaji University, Kolhapur India- 416004

6. Effective date of starting of the project   **:** 01/07/2015
   21/04/2016(Grant Received)

7. Grant approved and expenditure incurred during the period of the report:

   a) Total amount approved Rs   **:** Rs. 9, 59,000/- (Nine Lakh Fifty Nine Thousand only)

   b) Total expenditure Rs   **:** Rs. 4, 39, 924/- (Four Lakh Thirty Nine Thousand Nine Hundred Twenty Four only)

   c) Report of the work done: **Report Enclosed**

     i. Brief objective of the project: **(See Annexure-I)**

     ii. Work done so far and results achieved and publications, if any, resulting from the work (Give details of the papers and names of the journals in which it has been published or accepted for publication **(See Annexure-I)**

     iii. Has the progress been according to original plan of work and towards achieving the objective? if not, state reasons: **Yes**

iv. Please indicate the difficulties, if any, experienced in implementing the project: **No.**

v. If project has not been completed, please indicate the approximate time by which it is likely to be completed. A summary of the work done for the period (Annual basis) may please be sent to the Commission on a separate sheet. **The Project has been completed.**

vi. If the project has been completed, please enclose a summary of the findings of the study. One bound copy of the final report of work done may also be sent to University Grants Commission.

vii. Any other information which would help in evaluation of work done on the project. At the completion of the project, the first report should indicate the output, such as (a) Manpower trained (b) Ph. D. awarded (c) Publication of results (d) other impact, if any**(See Annexure-II)**

SIGNATURE OF THE PRINCIPAL
INVESTIGATOR

Dr. R. R. Mudholkar
Principal Investigator
UGC Major Research Project

REGISTRAR

Registrar
Shivaji University, Kolhapur

Objective

Studies on Fuzzy Logic Thermal Compensation Technique for High Speed Precision Machine.

Methodology

The entire research work will be consolidated as follows:

- Study temperature response of spindle at various rpm and develop transfer function.
- Simulation and performance study of fuzzy optimized cooling system controller using simulating tools of MATLAB.
- Hardware descriptions of the fuzzy logic controller (FUZZIER, RULE-BASE, and DEFUZZIER modules) in Altera Quartus Development Environment.
- Simulation and performance study of overall fuzzy optimized embedded system using simulating tools of MATLAB/ Altera Quartus Development Environment.
- After successful simulation, Implemention of the system hardware, which mainly consists of Sensor system, Signal conditioning and dedicated fuzzy logic controller design.
- Optimization of process through tuning approach if required.

Work done

 The literature survey reveals that temperature plays vital role in machine tool performance. The spindle system is the core component of machine tool structure and its performance dominates machine accuracy and productivity. Internal heat sources in machine tool cause temperature distribution in structures and resulting heat flow causes thermal deformation of component. The complex thermal behavior is the predominant factor for determining the performance of machine tool. As the important component in machine tool, the spindle would generate large amounts of heat when it is running at a high speed. The amount of heat generated results in thermal error. Thermal error can be reduced by a number of methods as **Thermal Error Avoidance method** can only be implemented in the phase of machine designing and construction. **Thermal Error Control** is used to control the amount of heat transferred into the spindle system or to avoid the generation of the non-uniform temperature distribution. In order to control the thermal error jacket cooling is used which is complex system. **Thermal error compensation** is more convenient and economical, as its principle is simple and can be easily executed in the factory with minimal cost. Therefore to eliminate the thermal error thermal compensation method has been used.

1. **Orientation of Research Problem**

In the proposed system temperature of main spindle will be measured by using temperature sensor. Since the temperature behavior of machine tool is nonlinear phenomena, handling the spindle deformation caused due to temperature becomes relatively a complex problem. Fuzzy logic control can tackle such complex problem precisely and FLC is inherently robust since it does not require precise, noise-free inputs. Present work proposes to use two inputs–single output (MISO) fuzzy logic control system aiming at maintaining the temperature of machine tool spindle within deformation limits. The Figure 1 shows the block diagram of proposed system.
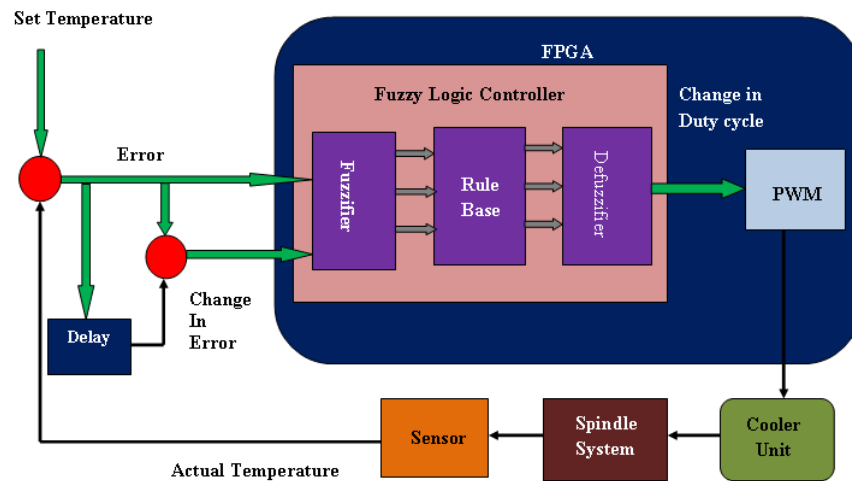
Figure 1: FPGA Based Fuzzy Logic Temperature Controller

Many fuzzy control applications with the physical systems require a real-time operation to interface high speed constraints, higher density programmable logic devices such as field programmable gate array (FPGA) can be used to integrate large amounts of logic in a single IC. Higher density programmable logic device such as FPGA can be used to integrate large amounts of logic in a single IC. FPGA becomes one of the most successful of technologies for developing the systems which require a real time operation. Therefore proposed system aims at compensating the temperature of spindle of a machine tool using thermoelectric cooler.

2. **System Prototype Construction (Finalization of System Component)**

Prototype of system has been developed to compensate the temperature of spindle of machine tool using FPGA Based Fuzzy Logic Temperature Controller. The system prototype consists of Machine Tool Spindle unit assembly and Thermoelectric Cooler Module.

a. **Machine Tool Spindle unit assembly**

The machine tool spindle unit assembly consist of

- Spindle
- AC Motor

- VFD (Variable frequency drive)
- Belt-Pully system
- Brake system

The spindle is externally driven by single to three phase asynchronous ac motor. The maximum rpms (revolutions per minute) of the motor are 2800. It is Series Motor, It has 2 poles, delta connected and has power of 1 HP. In order to obtain variable speed (rpm) Variable frequency drive (VFD) has been used. Its input is single phase while output is three phase. It can change frequency from 0.1 Hz to 600 Hz. A variable frequency drive controls the speed of an AC motor by varying the frequency supplied to the motor. The drive also regulates the output voltage in proportion to the output frequency to provide a relatively constant ratio of voltage to frequency (V/Hz) . In verge of the obtaining the spindle roational speed higher than 2800 the belt-pully system is being employed. The driver pulley and driven pulley diameter are selected in the 7:3 ratio. So the speed of spindle will increase seven times greater than that of motor speed. The roatational speed (rpm) of spindle are measured by using non-contact tachometer. In the present system there is no load hence braking system is designed to apply radial friction on spindle. Therefore with friction applied heat will be generated.The photo of machine tool spindle tool assembly is displayed in Figure 2.
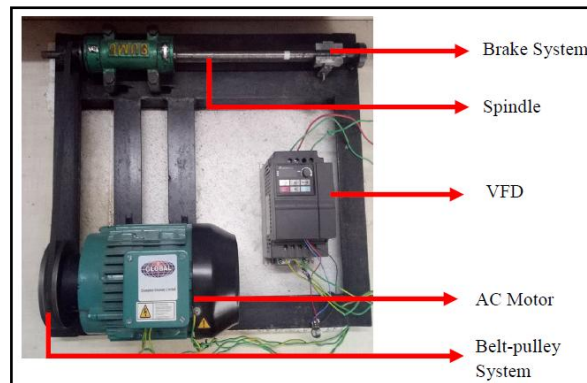
Figure 2: Machine Tool Spindle Unit Assembly (Top View)

b. Thermoelectric Cooler

Figure 3: Picture of Thermoelectric Cooler Module

The Thermoelectric cooler Module containing peltier element TEC1-12706 is used which has maximum cooling power of 57 watt and maximum operating temperature is 67 ^{0}C. It can directly

powered by DC electricity sources TEC1-12706 operates on 12 V, 6 Amp DC supplies. The peltier element has two sides hot and cold. In the TEC model the cold side of TEC is attached to the cooling load component and heat sink is attached on the hot side. The cooling side of the TEC is forced by a fan that carries cool air onto the spindle. The heat from the load is absorbed by cooling side and heat produced on the hot side is pumped away in the atmosphere by using the heat sink.
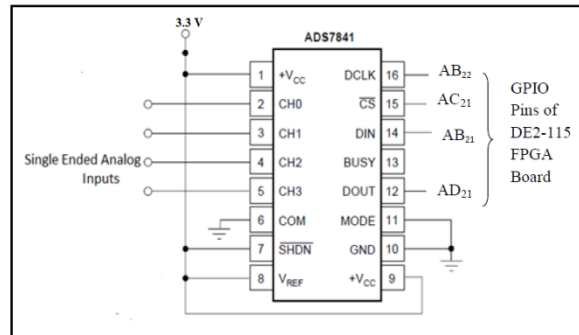
3. Data Acquisition System

Figure 4: Connection Diagram of ADC with the FPGA Board

In order to measure the temperature of spindle of machine tool FPGA based data acquisition system has been designed and implemented.
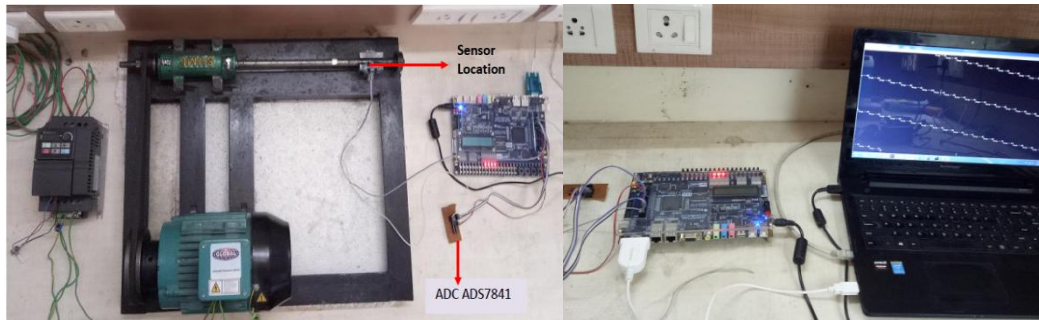
Figure 5: Data Acquisition System

With the help of Data Acquisition system the temperature of spindle was measured. 1000 to 4500 rpm. The transfer function estimated presented in Table 1. The transfer function was estimated and simulated using Matlab-Simulink.

Table 1:Transfer Functions

Sr. No.	Rotational speed(rpm)	Transfer Function
01	1000	$G(s) = \dfrac{4.88}{513s + 1}e^{-50s}$
02	1500	$G(s) = \dfrac{7.81}{245.5s + 1}e^{-20s}$
03	2000	$G(s) = \dfrac{8.79}{346s + 1}e^{-20s}$
04	2500	$G(s) = \dfrac{9.76}{356s + 1}e^{-11s}$

05	3000	$G(s) = \dfrac{10.25}{322.75s+1}e^{-10.5s}$
06	3500	$G(s) = \dfrac{15.12}{316s+1}e^{-0s}$
07	4000	$G(s) = \dfrac{16.6}{435.7s+1}e^{-0s}$
08	4500	$G(s) = \dfrac{18.07}{386.6s+1}e^{-0s}$

Transfer Function of Thermoelectric Cooler

$$G(S)= \frac{Temperature}{Current} = \frac{-2.6}{50s+1}e^{0s} \tag{1}$$
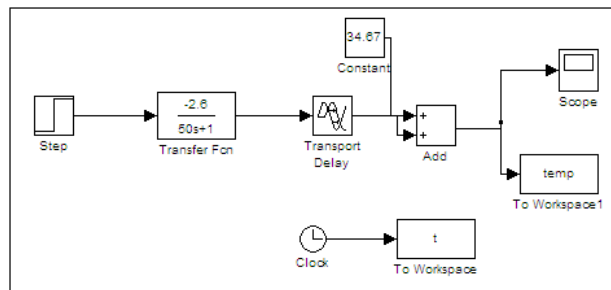
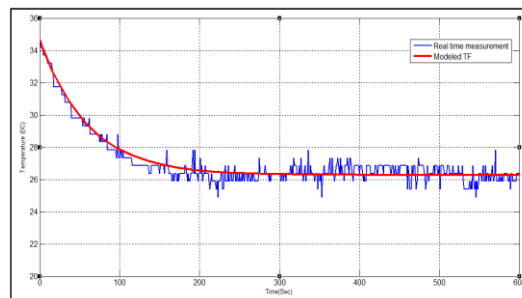Figure 6: Simulink Model for Testing Estimated TF of Thermoelectric Cooler.
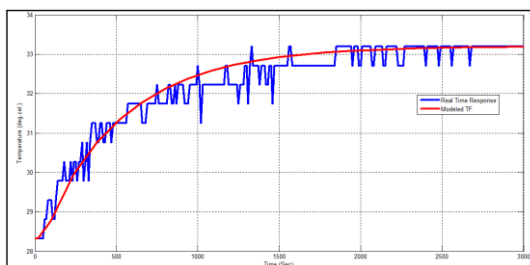

Figure 7:Comparison between real time response and modeled TF response

Figure 7:spindle Temperature at 1000 rpm
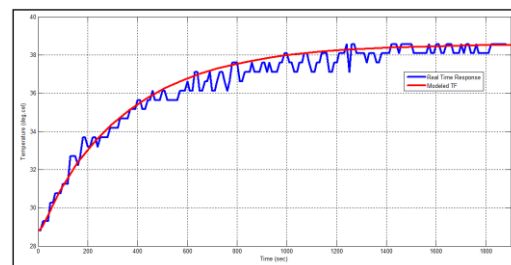
Figure 8:Spindle Temperature at 1500 rpm
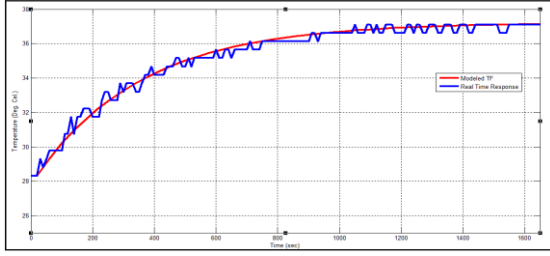
Figure 9:spindle Temperature at 2000 rpm
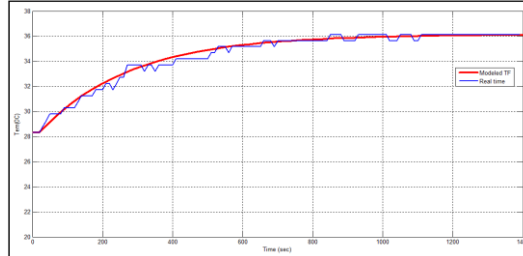
Figure 10:spindle Temperature at 2500 rpm
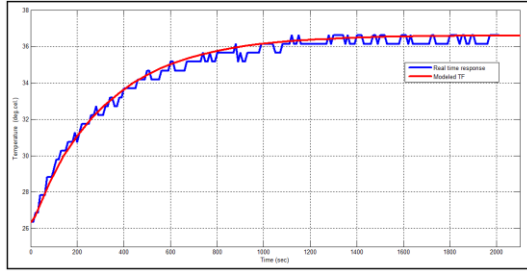
Figure 11:spindle Temperature at 3000 rpm
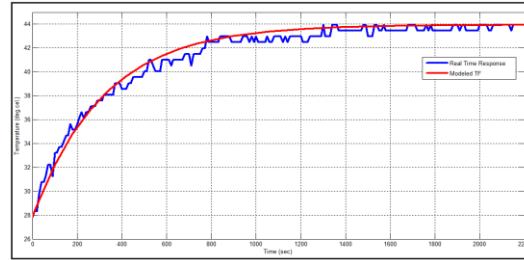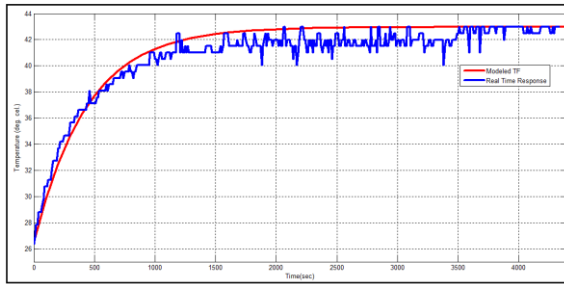

Figure 12:spindle Temperature at 3500 rpm

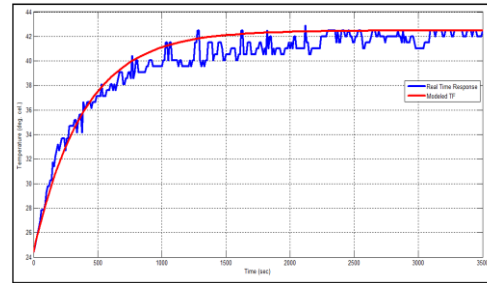Figure 13:spindle Temperature at 4000 rpm

Figure 14:spindle Temperature at 4500 rpm

The real time response and simulated response are in good agreement. The simulation response of rpm from 1000 to 4500 rpm plotted together. The plot shows that as the rotational speed increases the temperature of spindle increases.
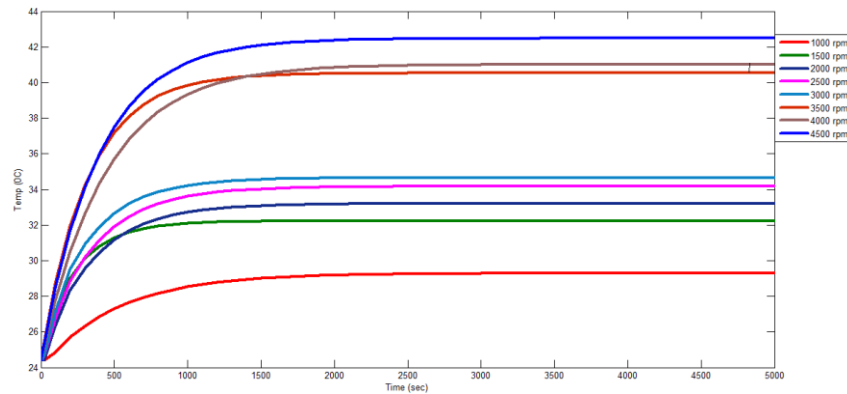

Figure 15 : Thermal Behaviour Analysis

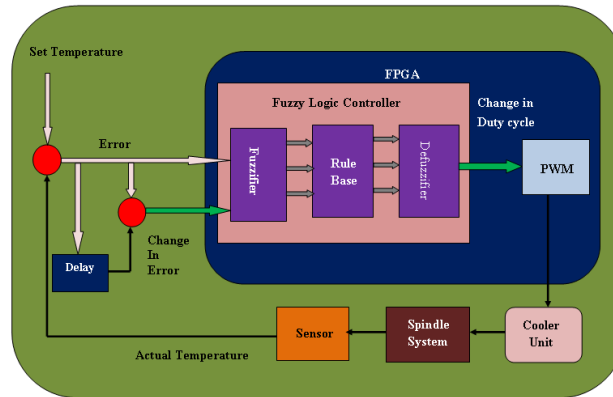## 4. Fuzzy Temperature Controller Implementation

Figure 16: Structure of Fuzzy Temperature Controller

Fuzzy Temperature controller system consist of standard reference temperature, processing unit, plant and feedback system. The reference temperature is set during the programming of processing unit. The processing unit used for the implementation of fuzzy temperature controller is Altera Cyclone IV EP4CE115F29 FPGA device (DE2-115 FPGA Board). The fuzzy controller implemented in FPGA will produce control signal i.e. PWM (pulse width modulation) signal. This PWM output will drive the thermoelectric cooler module. TEC1-12706 thermoelectric cooler has been used for the cooling of spindle unit. The fuzzy temperature control system is as shown in Figure 16. The temperature feedback is applied using FPGA based temperature data acquisition system. The fuzzy temperature controller is implemented in Fuzzy Logic. The feedback signal is processed using FPGA and error, change in error these signals are engendered and control signal is generated through FPGA to control the speed of Thermoelectric Cooler to compensate the temperature of spindle of machine tool

4.1. PWM Driver Circuit

PWM (Pulse width modulation) is used to control the power of thermoelectric cooler in order to maintain the temperature of spindle of a machine tool within a required range. In industrial application for refrigeration H Bridge has been used which provides required power for cooling as well as heating as per the application. In present system heat is generated so cooling is required. Therefore only one section of H-Bridge containing driver IC U1 and MOSFET Q_1 and Q_2 was used for cooling purpose. Thermoelectric cooler uses peltier element that can be used for heating or cooling purpose. If the supply to the peltier is given in accurate polarity then it provides cooling and if the polarity is reversed then heating occurs. Here we are using peltier for cooling. This circuit accepts the PWM gating pulses by implementing fuzzy temperature controller in FPGA and provides control output to the TEC to maintain the temperature of spindle within a range.
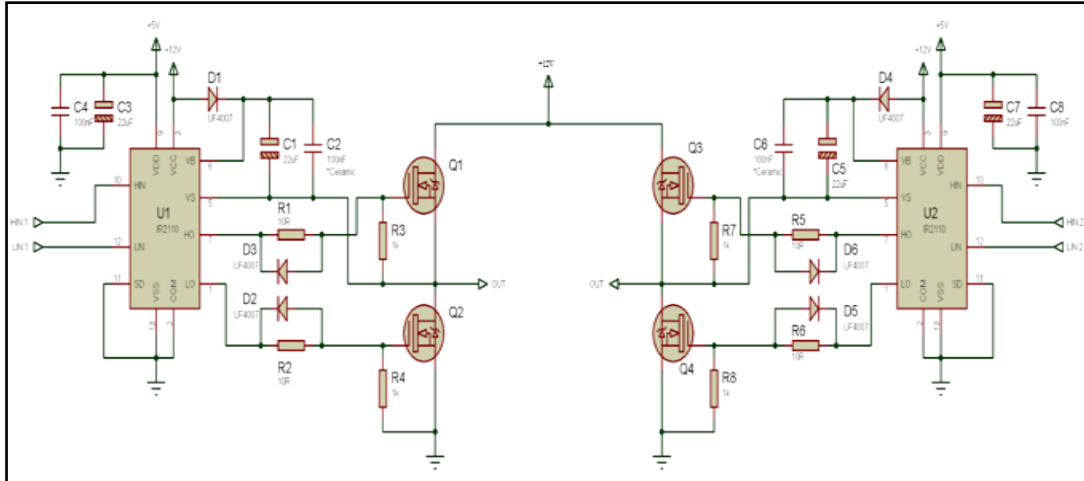
Figure 17 : PWM driver circuit

To put together voltage level of PWM driver circuit (See Figure 17) compatible with FPGA Board that supplies on board 3.3 V supplies, voltage regulator IC LM 1117 has been used which provides 3.3 V regulated supply (See Figure 18). The 12 V input supply is given through 12V/10 Amp SMPS and generated output was provided to the H-Bridge.
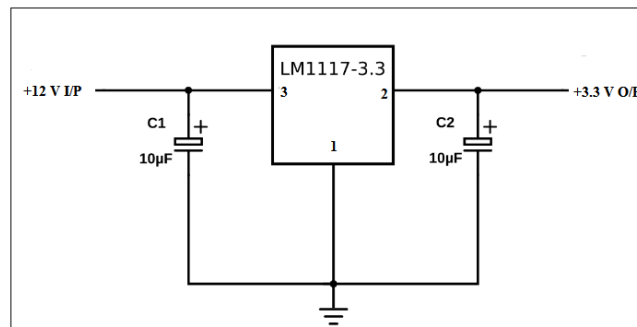

Figure 18: LM 1117 voltage Regualtor

In the driver circuit Power MOSFET IRF 840 is used as switching device which is connected in series with the TEC. It provides fast switching speed. IRS 2110 is high voltage, high speed N-Channel power MOSFET driver with two separate channels for high and low side reference voltage. It is operational up to 500 V/ 600 V and provides output up to 10 V to 20 V. It is compatible to voltage level of 3.3 V.

4.2. PWM Implementation

Thermoelectric cooler is driven by PWM (pulse width modulated) signal. The duty cycle of PWM signal is controlled by fuzzy controller. In fuzzy temperature controller the temperature of spindle of machine tool is measured by IC sensor is feeded back.
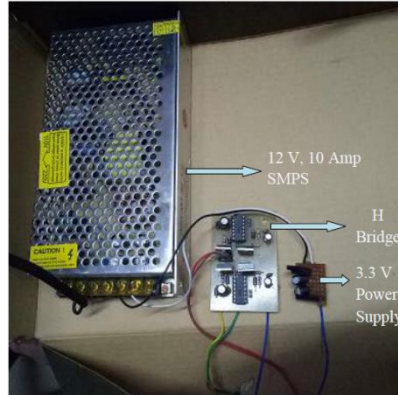
Figure 19: Photo of H Bridge

The difference between the standard reference temperature and the present temperature is computed as error and it is applied as input to the fuzzy controller. This error is processed by fuzzy controller to find out the percentage of error and generate the required amount of PWM signal to retain the temperature of spindle of a machine tool at specified value. The PWM is implemented in FPGA that generates PWM signal of 1 KHz (See Figure 20).

Figure 20: PWM Waveform Generation

5. Matlab simulation of Fuzzy Logic Controller

The fuzzy temperature controller has been designed and simulated using Fuzzy Logic Tool Box and Simulink of Matlab Ver 2015b. The Simulink model for MISO (Many Input and Single output) displayed in Figure 21. It has two inputs Error and Change in Error these inputs are processed by fuzzy logic temperature controller and provides the control signal to the TEC. The input and output membership functions used in the fuzzy controller are shown in. Figure 22 and. Figure 23 and Figure 24. The range of input and output variables is represented in Table 2. The rules are represented in Table 3.
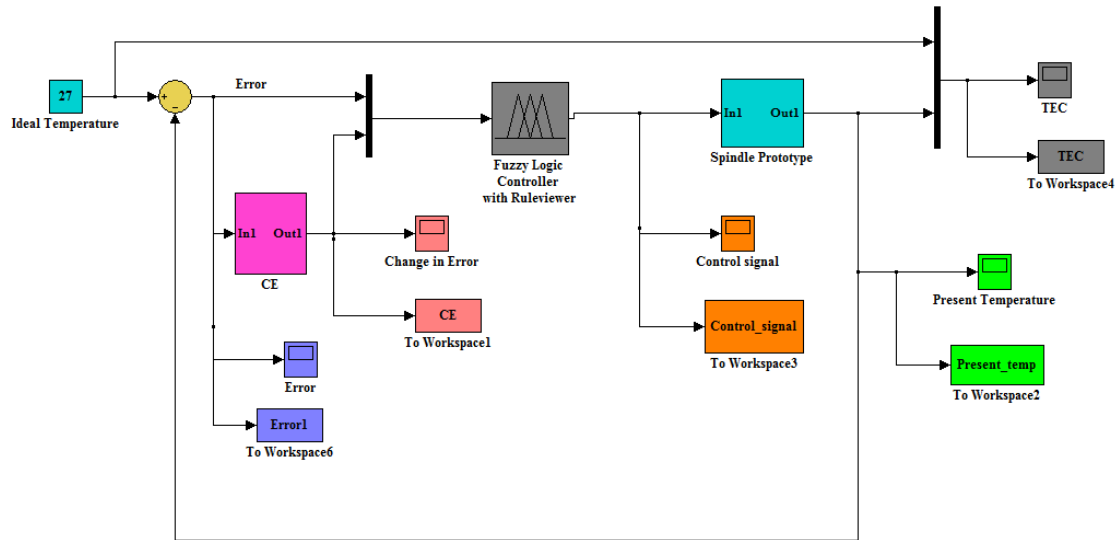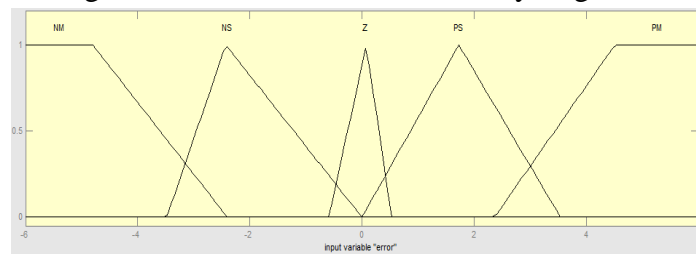
Figure 21:Simulink Model for Fuzzy Logic Controller

Figure 22: Membership Function for Input Variable "error"
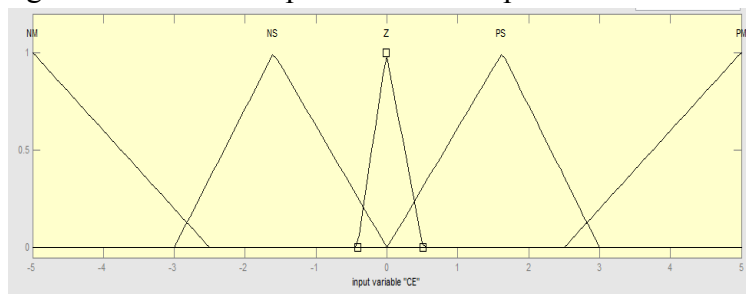

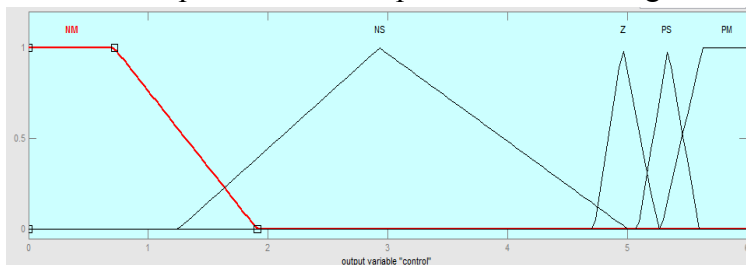Figure 23: Membership Function for Input Variable "Change in Error (CE)"

Figure 24: Membership Function for Output Variable "Control Signal"

Input and Output membership functions contains trapezoidal and triangular membership functions.

Table 2: Input and output range of linguistic variable

Sr. No	Input Variable Name	Crisp Input Range of "Error"	Crisp Input Range of "Change in Error (CE)"	Crisp Output range "Control Signal"
01	NM	[-5 -5 -4 -2]	[-5 -5 -2.5]	[0 0 0.7 2]
02	NS	[-2.9 -1.5 0]	[-3 -1.8 0]	[1 2.15 3.7]
03	Z	[-0.5 0 0.5]	[-1 0 1]	[3.4 3.7 3.9]
04	PS	[0 1.9 3.5]	[0 1.8 3]	[3.7 4.5 5.3]
05	PM	[2 4 5 5]	[2.5 5 5]	[4.65 5.3 6.6]

Table 3. Control Rules

Control		Change in Error (CE)				
		NM	NS	Z	PS	PM
Error	NM	PM	PM	PM	PS	Z
	NS	PM	PM	PS	Z	NS
	Z	PM	PS	Z	NS	NM
	PS	PS	Z	NS	NM	NM
	PM	Z	NS	NM	NM	NM

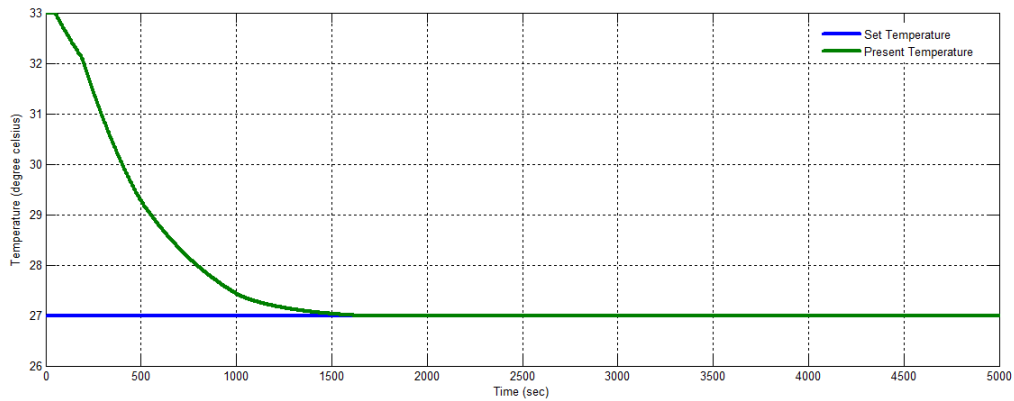The result of simulation has been displayed in Figure 25.

Figure 25: Set point achieved

From the Figure 25 it is observed that the spindle temperature reached up to 33^0 C at 1000 rpm. For

the demonstration purpose 27^0C is chosen as Ideal Temperature for a spindle system prototype. Thermoelectric cooler is able to reduce the temperature by 6^0 C.
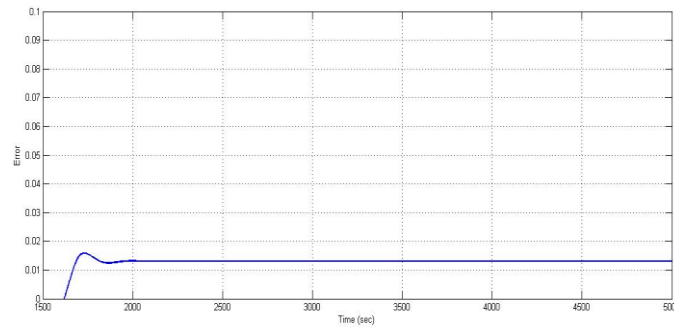
Figure 26: Error Obtained

Figure 26 shows the result of simulation of spindle system prototype. The simulation is performed from 0 to 5000 sec. The Error in simulation is 0.015^0 C that is $\pm$ 0.25%. The settling time for the simulation is 2000 sec. Figure 28 shows the output control signal generated by Fuzzy Logic Temperature Controller that supplied to the Thermoelectric Cooler that compensate the temperature of spindle. The control signal settles down at 2900 rpm.

Figure 27: Change in Error (CE)

Figure 28: Control Signal

Figure 29: Three dimensional surface view

6. Implementation of Fuzzy Temperature Controller in FPGA.

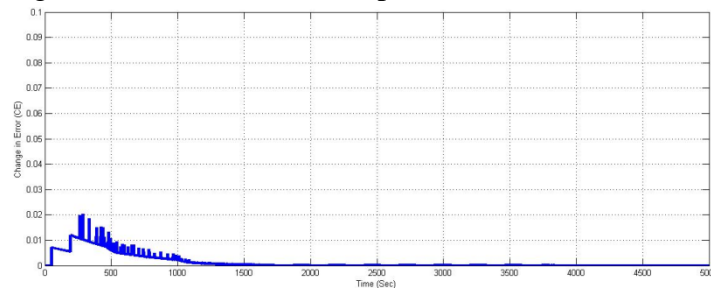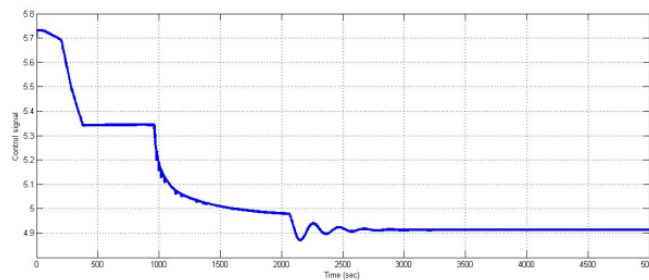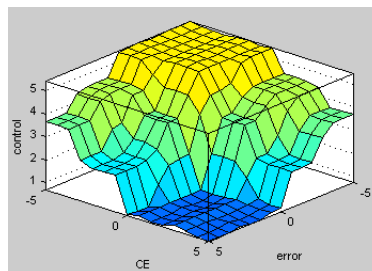The fuzzy temperature controller has been implemented to compensate the temperature of the spindle at 1000 rpm. In the present system the fuzzy logic temperature control has been implemented by using software/Hardware Codesign approach on FPGA board. The hardware system has been implemented using SOPC builder tool that is Qsys in combination with Quartus prime Edition 15.1. Qsys allows creating a system based on Nios II Processor. The inputs to the fuzzy temperature controller are error (E) and change in error (CE) and the output signal of controller is connected to Pulse Width Modulation (PWM) Generator. PWM controls the cooling of Thermoelectric Cooler by changing its current which controls the temperature of spindle. The simulation and performance study of fuzzy Logic Temperature Controller (FLTC) has been performed with MATLAB. The Nios II processor software has been written in C language using the Nios II IDE software provided by Altera that is NIOS II Software Build Tool (SBT) for Eclipse. The hardware and software has been implemented on Cyclone IV EP4CE115F29C7 DE2-115 FPGA Board. The design flow of the system has been displayed in Figure 30.
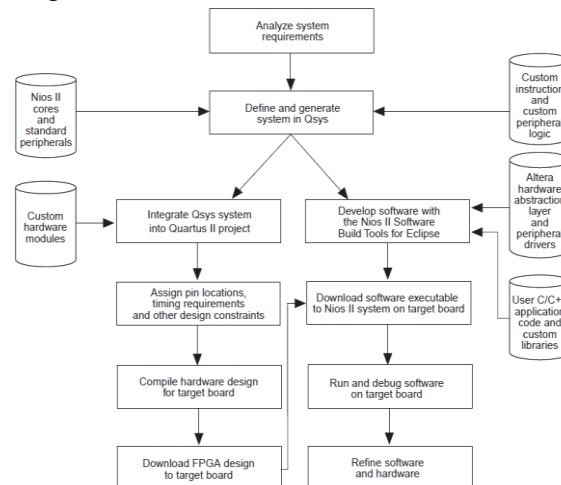

Figure 30: Hardware and software codesign

6.1. Implementing System using NIOS II soft core processor

Altera's Nios II is a soft processor, defined in a hardware description language that can be implemented in altera's FPGA devices by using the Quartus II CAD system. The Nios II processor and the interfaces are interconnected to other components of FPGA board by means of the interconnection network called the Avalon Switch Fabric Network. I/O interfaces are instantiated to offer I/O connections to the system. The JTAG UART interface provides connection between universal serial bus (USB) links providing circuit that is USB blaster and the host computer to which DE2-115 FPGA Board has been connected. The USB blaster along with JTAG module makes it possible to perform operations such as downloading programs into memory, starting and stopping execution, setting program breakpoints, and collecting real-time execution trace data. By using USB Blaster circuitry host computer can control Nios II processor. The Component required for implementation of Nios II System is displayed in Figure 31.
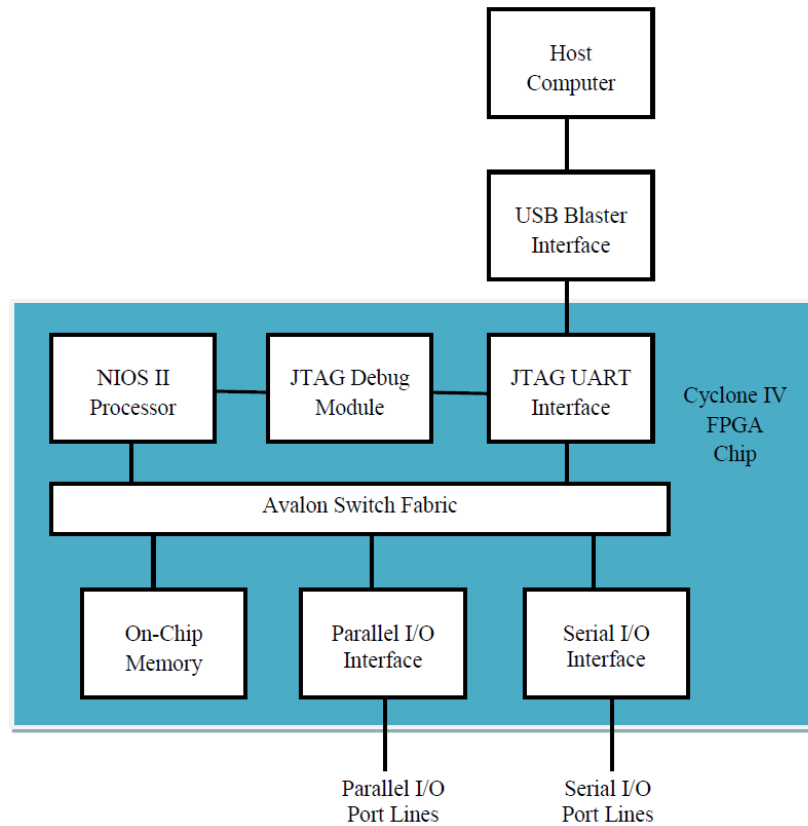
Figure 31: A Nios II System Implemented on FPGA Board

6.2. Implementation of the Nios System with Qsys Tool

The temperature of spindle of a machine tool has been compensated by using fuzzy logic that is implemented in FPGA. The system to be implemented is displayed in Figure 32. The DE2-115 FPGA board has been used. The temperature of spindle of a machine tool has been measured with the IC temperature sensor LM 35. In order to process the analog data into digital and to record the real time temperature analog to digital converter is required. As the FPGA board has no ADC therefore external ADC ADS 7841 has been interfaced with the FPGA. In order to provide required cooling to control the temperature of spindle of machine tool thermoelectric cooler TEC1-12706 has been used. The control signal is generated through PWM circuit which is interfaced with the FPGA board. The control signal has been generated by fuzzy temperature controller. Field Programmable Gate Arrays (FPGA) provides very good hardware design flexibility. The thermoelectric cooler TEC-12706 requires operating voltage 0 to 12 V and current of 6 Amp. The advantage of using FPGA is that it is used to generate High-frequency variable duty cycle PWM output. The DE2-115 Board contains an FPGA that can be programmed that it includes NIOS-II soft core processor.

All components are interfaced with the GPIO pins of FPGA Board. The Quartus software 15.1 along with Nios II Embedded design suit (EDS) has been used to develop Nios II hardware system design that create software program that runs on Nios II system and the components are interfaced on Altera development board.
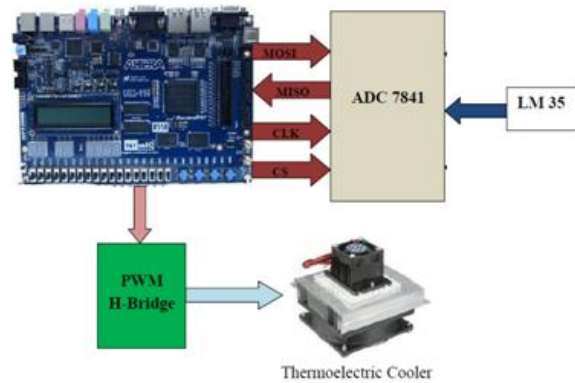
Figure 32:The FPGA Based system

6.3 The Quartus Software

Altera Quartus II is programmable logic device design software produced by Altera. Quartus II software features include SOPC Builder and Qsys tool. SOPC builder tool in Quartus II software that eliminates manual system integration tasks by automatically generating interconnect logic and creating a test bench to verify functionality while Qsys is a system integration tool that is the next generation of SOPC Builder.

Figure 33: Quartus Prime Development Suite.

6.4 System Generation through Qsys Tool

The Qsys tool allows a designer to choose the components that are desired in the system by selecting these components in a graphical user interface. It then automatically generates the hardware system that connects all of the components together.

In order to implement the system following functional units are used.

- Nios II processor
- On-chip memory
- Two parallel I/O interfaces
- JTAG UART interface for communication with the host computer
  The following steps are performed to implement the system

Quartus Software

↓

Create a Project
Define Top Level Entity
Assign Device and Family

↓

Select Qsys Tool

ON Chip
Memory   50 MHZ clock   LCD Component   Parallel I/O   UART
                          Nios II   Interface
                          Processor

↓

Make necessary Connections

↓

Define base addresses

↓

Compile a system

↓

Generate VHDL Code

↓

Integration of the Nios II System into a Quartus Prime Project

↓

Assign the FPGA pins

↓

Compile whole Quartus Prime project

The designed circuit has been compiled. The system has been compiled successfully the result of compilation was displayed in Figure 34.
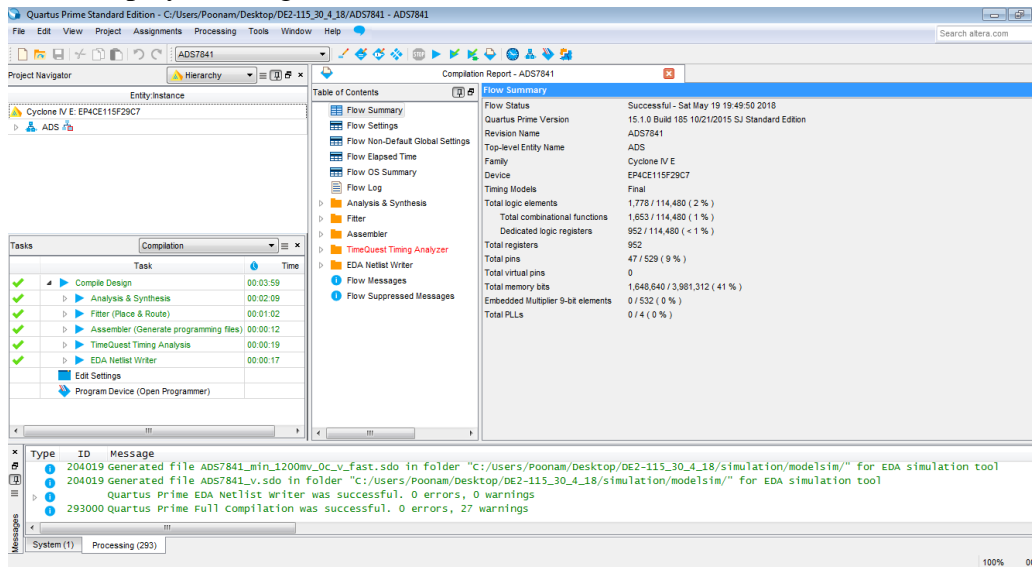

Figure 34:Compilation Result

After the successful compilation device utilization report is obtained. That is represented in Table 4.

Table 4. Device Utilization Report

	Used	Available	Utilization
Total Logic Elements	1,778	114,480	2 %
Total combinational functions	1,653	114,480	1 %
Dedicated logic registers	952	114,480	< 1 %
Embedded Multiplier 9-bit elements	0	532	0
Total registers	952	--------	------
Total Pins	47	529	9%
Total memory bits	1,648,640	3,981,312	41 %
Total PLLs	0	4	0%

From the Table 7, it has been observed that utilization of logic elements is only 2% that is 1,778 elements out of 114,480 elements are used. Total combinational functions used are 1,653 that is 1% and use of dedicated logic registers less than 1%.

6.5. Programming and Configuring the FPGA device on the DE2-115 board

After successful compilation programmer has been selected from the tool option. The

hardware set up displays the present hardware. USB Blaster 0 has been selected as displayed Figure 35.a. then .sof file has been added program has been running on the hardware as displayed in Figure 35.b. After running the program the result is displayed on FPGA Board as shown in Figure 36.
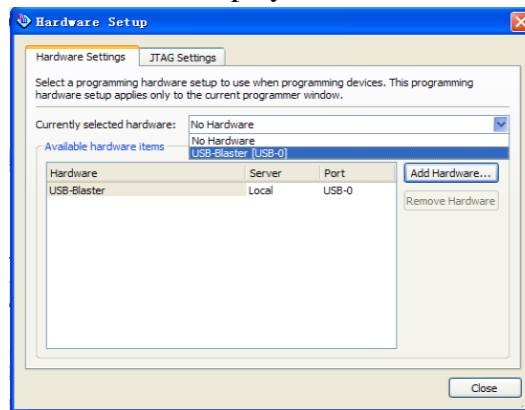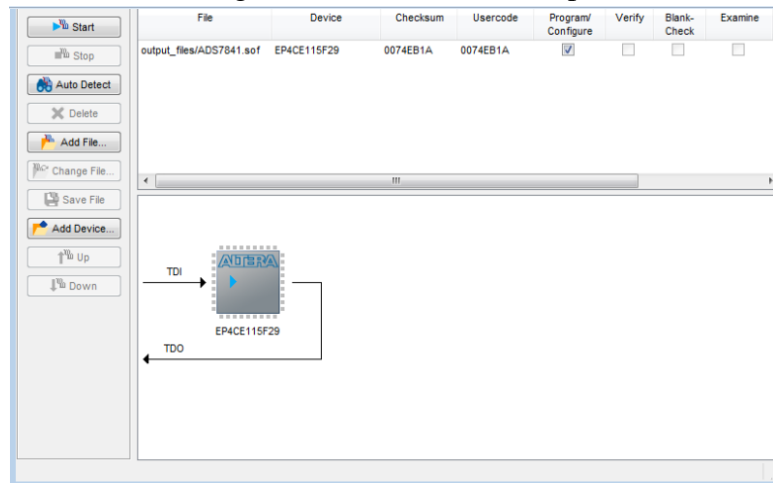

Figure 35.a. Hardware Set up

Figure 35. b. Hardware Set up
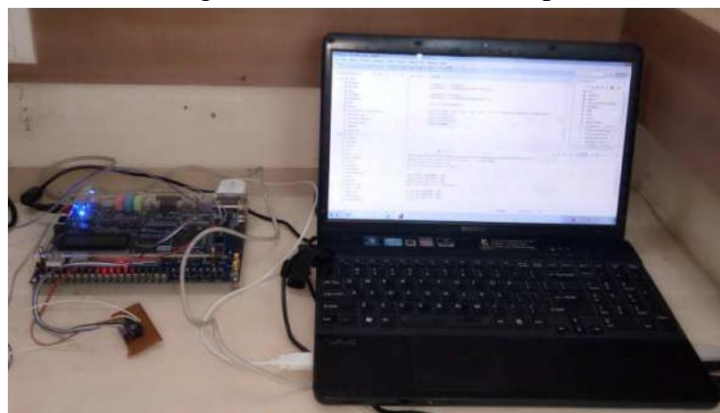
Figure 36: Program Execution on FPGA Board

6.6 Nios II Software Development Tool (SBT) for Eclipse

The software development task has been performed for Nios Processor system by using Nios II software development tool (SBT) for Eclipse. The system was generated with Qsys then C application code has been designed with the Nios II SBT for Eclipse. The following steps are performed

Nios II Software Development Tool

⇩

Nios II Eclipse application

⇩

Select a Workspace

⇩

Select NIOS II Application and BSP from Template

⇩

Select SOPC Information file and location

⇩

BSP_ADC_bsp board support package generated.

⇩

BSP_ADC is a C application project created

⇩

BSP_ADC_bsp board support package generated.

⇩

Build and Run the Program on FPGA Board
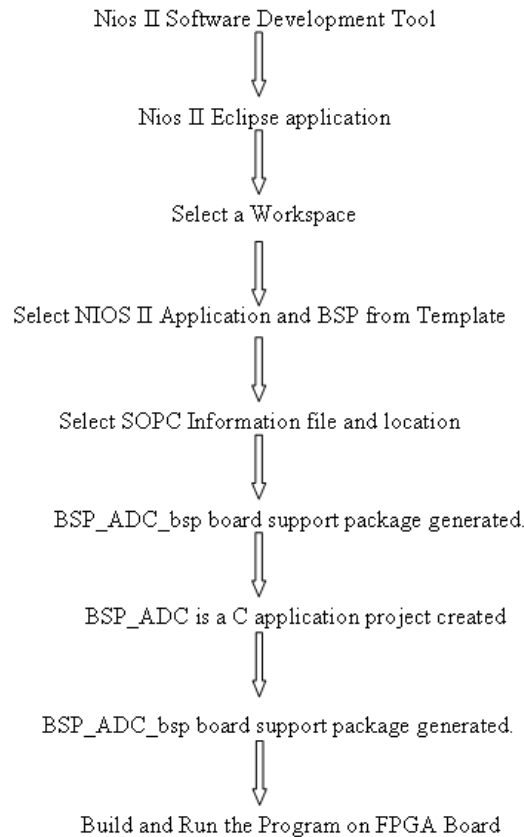
After running the program on FPGA Board the spindle temperature starts compensating the spindle temperature as displayed in Figure 37.

Figure 37: Implementation of FPGA Based Fuzzy Logic Spindle Temperature Compensation.

The Figure 37 shows FPGA Based Fuzzy Logic temperature controller to compensate the temperature of spindle of machine tool. The result of compensation is displayed in Figure 38. The result of 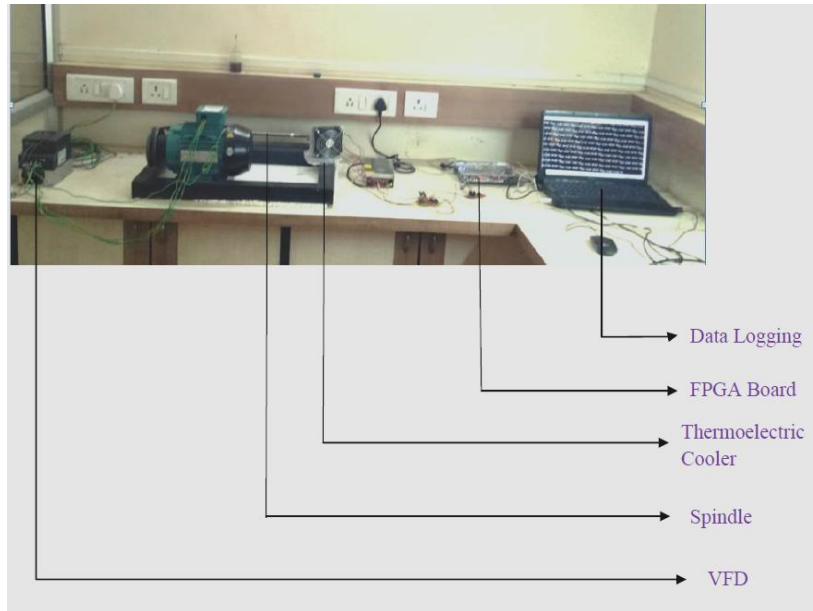compensation presents that the spindle temperature which reached up to 33^0C after compensation it attains the set temperature of 27^0C.
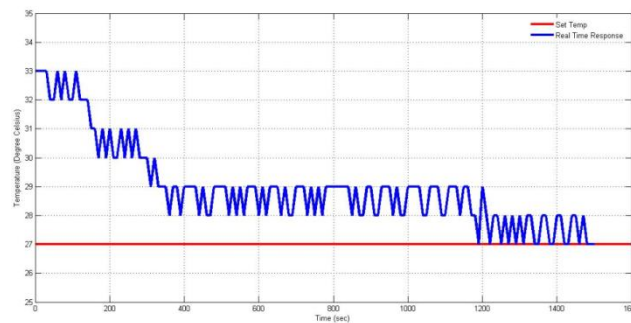
Figure 38. Real time Response of spindle temperature compensation system implemention.

The time response of spindle temperature compensation system shows that the system has time delay of 30 Sec and the system settles down after 1480 seconds.

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4. Patil, P. S., and Mudholkar, R. R. (2016). Cooling Techniques for a Spindle of Machine Tool, International Journal of Engineering and Computer Science, 5 (12), 19653-19656.

5. Lacalle, N. L. D., and Mentxaka, A. L. (2008), Technology & Engineering e-book on Machine Tools for High Performance Machining, https://books.google.co.in/books?isbn=1848003803.

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7. Chiller Wikipedia: https://en.wikipedia.org/wiki/Chiller. Browsed on October 2017.

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1. Poonam S. Patil, R. R. Mudholkar, "Cooling Techniques for a Spindle of Machine Tool", International Journal Of Engineering And Computer Science, Volume 5 Issue 12 Dec. 2016, PP: 19653-19656.

2. Poonam S. Patil, R. R. Mudholkar, "Thermal Error Modeling In Machine Tool", International Journal of Engineering Science and Technology (IJEST), pp:344-352, Vol. 9 No.05 May 2017

3. Poonam S. Patil, R.K. Kamat, R. R. Mudholkar, "TF Estimation and Thermal Behavioral Analysis of Spindle Cooler System", Research Journal of Engineering and Technology. 9(1): January- March, 2018.

Conference

1. Poonam S. Patil, R.R. Mudholkar "Student Performance Evaluation By Different Defuzzification Techniques" International Interdisciplinary Conference On Curriculum Reformsin Higher Education: Global Scenario (IICCRHE-2018) February 4-6, 2018.

Sr. No	Title	Name
a)	Manpower Trained	Poonam Siddu Patil (Project Fellow)
b)	Publications of Result	1. Poonam S. Patil, R. R. Mudholkar, "Cooling Techniques for a Spindle of Machine Tool", International Journal Of Engineering And Computer Science, Volume 5 Issue 12 Dec. 2016, PP: 19653-19656. 2. Poonam S. Patil, R. R. Mudholkar, "Thermal Error Modeling In Machine Tool", International Journal of Engineering Science and Technology (IJEST), pp:344-352, Vol. 9 No.05 May 2017 3. Poonam S. Patil, R.K. Kamat, R. R. Mudholkar, "TF Estimation and Thermal Behavioral Analysis of Spindle Cooler System", Research Journal of Engineering and Technology. 9(1): January- March, 2018.
c)	Ph.D awarded	Ph.D Registered Student Name: Poonam Siddu Patil Guide Name: Dr. R. R. Mudholkar Date of Registration:01/07/2015 Spiral Bound Ph.D Thesis submitted for Scrutiny. Title of Thesis: FPGA Based Fuzzy Logic Spindle Temperature Compensation

UNIVERSITY GRANTS COMMISSION
BAHADUR SHAH ZAFAR MARG
NEW DELHI – 110 002

PROFORMA FOR SUBMISSION OF INFORMATION AT THE TIME OF SENDING
THE FINAL REPORT ON THE WORK DONE ON THE PROJECT

1.	Title of the project	:	Studies on Fuzzy Logic Thermal Compensation Technique for High Speed Precision Machine
2.	Name and Address of the Principal Investigator	:	Dr. Mudholkar Ravindra Ramchandra Shivam, 5, Jadhav Park, Line Bazar Kasaba Bawada Kolhapur, INDIA – 416006. Mob. No.:-9637774815, Email : rrm_eln@unishivaji.ac.in
3.	Name and Address of The Institution	:	Department of Electronics Shivaji University, Kolhapur, India – 416004
4.	UGC Approval Letter No. and Date	:	F.No.-43-299/2014(SR) dated 29 December 2015
5.	Date of Implementation	:	01/07/2015 22/04/2016(Grant Received)
6.	Tenure of the Project	:	3 Years w. e. f 01/07/2015
7.	Total Grant Allocated	:	Rs.9,59,000/- (Nine Lakh Fifty Nine Thousand Only)
8.	Total Grant Received :	:	Rs.5,99,000/- (Five Lakh Ninety Nine Thousand Only)
9.	Final Expenditure	:	Rs.4,39,924/- (Four Lakh Thirty Nine Thousand Nine Hundred Twenty Four Only)
10.	Title Of The Project	:	Studies on Fuzzy Logic Thermal Compensation Technique for High Speed Precision Machine
11.	Objectives of The Project:	:	To design and implementation of Real Time Thermal Compensation of High Speed Precision Machine by Using the Fuzzy Control of The Cooling System.

12.	Whether Objectives Were Achieved:(Give Details)	:	Objectives were achieved.

Objectives were achieved.

The following objectives has been successfully achieved

- To design and fabricate the laboratory scale machine spindle system.
- To design and implement the signal conditioning system for temperature control system.
- To design and implement fuzzy control algorithm for temperature controller.
- To generate VHDL coding for fuzzy inference
- To implement the Fuzzy Logic Control Algorithm in FPGA.
- To present the system response analysis and performance of proposed system.

13. Achievements from the Project : Real Time Thermal Compensation of High Speed Precision Machine by Using the Fuzzy Control of The Cooling System has been achieved.

14. Summary of the Findings: (In 500 Words) : **See Annexure I**

15. Contribution to the Society (Give Details) :

- The fuzzy temperature control system for spindle of machine tool based on FPGA using thermoelectric Cooler is unique due to its simplicity**.**

- Present system uses the standard temperature maintaining approach which is suitable for all type of machine than predictive type of machine.

- Due to reconfigurable hardware platform the system adopted for other machine tool with some changes.

16. Whether Any Ph.D Enrolled/ Produced Out Of The Project: :

Registration Date: 01/07/2015
Name of research student: Poonam Siddu Patil
Research Topic: FPGA based Fuzzy Logic Spindle Temperature Compensation
Research Guide: Dr. Mudholkar Ravindra Ramchandra
Spiral Bound Ph.D Thesis submitted for Scrutiny.

17.	No. Of Publications Out Of The Project: (Please Attach)	:	**Published:** Poonam S. Patil, R. R. Mudholkar, "Cooling Techniques for a spindle of Machine Tool", International Journal of Engineering and Computer Science, Vol: 5(12), 2016, pp-19653-19656.

Published: Poonam S. Patil, R. R. Mudholkar, "Thermal Error Modeling in a Machine Tool" International Journal of Engineering Science and Technology. Vol:9(5), 2017,pp:344-352

Published: Poonam S. Patil, R. K. Kamat, R. R. Mudholkar, "TF Estimation and Thermal Behavioral Analysis of spindle cooler System Prototype" Research Journal of Engineering and Technology, Vol:9(1),2018, pp:37-44.

PRINCIPAL INVESTIGATOR

Dr. R. R. Mudholkar
Principal Investigator
UGC Major Research Project

REGISTRAR

Registrar
Shivaji University, Kolhapur

Summary of the Findings:

Machine tool is a stationary power-driven machine that is used to shape or form parts made of metal or other materials. The spindle is the drive component of machine tool. The belt driven spindle is used in the present system. The spindle generate large amount of heat as the rotational speed increases. This changes property of material that results in thermal error. Thermal error can be reduced by using thermal error avoidance method, thermal error control and thermal error compensation method. Thermal error compensation method is used it can be implemented in any stage of machine from designing to working. IC sensor is used to measure the temperature of spindle since it has good linearity, wide power range, and it is small and easy to install so that no compensating circuit is needed. In the present system two inputs–single output (MISO) fuzzy logic control system aiming at maintaining the temperature of machine tool spindle within deformation limits. A large number of fuzzy control applications require a real-time operation to interface high speed constraints. As the FPGA's becomes one of the most successful of technologies for developing the systems for a real time operation.

In order to compensate the temperature of spindle of machine tool thermoelectric cooling method has been used. Air to air thermoelectric cooler consisting of peltier element with two passive heat sinks on both sides are used. As the industrial standard temperature is 20^0 C the Single Input and Single output (SISO) system and Many Input and single output (MISO) system has been designed and implemented. Matlab-Simulink is used for the simulation of SISO and MISO system.

The different method of cooling are discussed, and the thermoelectric cooling method was explained. Transfer function of already existing thermoelectric cooling system has been studied. The work presents the simulation result of fuzzy temperature controller to achieve the set temperature of 20^0 C and 27^0 C. It also presents the resulting temperature after compensation.

System prototype has been constructed to measure the spindle temperature of machine tool. Prototype consists of spindle, VFD (Variable frequency drive) connected to the AC Motor that drives the spindle with belt and pulley system. Brake system is used to apply the radial friction so heat can be generated. FPGA based data acquisition system has been designed. ADC

ADS 7841 is used to convert the analog information into digital. Real time response of temperature spindle at different rotational speed is measured and the transfer functions are estimated. Also, the cooling response of Thermoelectric Cooler is observed. For the simulation of transfer function of Matlab Simulink is used. In order to control the airflow of TEC PWM implemented in FPGA.

Fuzzy Logic Temperature Controller for the compensation of spindle temperature at 1000 rpm has been implemented by using Hardware-software codesign.Quartus prime Edition 15.1. Qsys was used to create a system based on Nios II Processor.The Nios II processor software has been written in C language using the Nios II IDE software provided by Altera that is NIOS II Software Build Tool (SBT) for Eclipse In order to compensate the temperature of spindle of machine tool, Fuzzy logic temperature controller is implemented in FPGA by using hardware and software codesign. The results of spindle temperature compensation are tested and verified.

- ➤ The Hardware platform
  Cyclone IV EP4CE115F29C7DE2-115 FPGA Board.
- ➤ The software platform
  Quartus prime Edition 15.1.
    - • Qsys tool
    - • NIOS II Software Build Tool (SBT) for Eclipse

After the successful compilation the system has been implemented on FPGA board. It was observed that total logic elements used are only 2 % that is 1,778. Total combinational functions used are only 1%.

Final Report Assessment / Evaluation Certificate
(Two Members Expert Committee Not Belonging to the Institute of Principal Investigator)
(to be submitted with the final report)

It is certified that the final report of Major Research Project sanctioned by UGC vide letter F.No.43-299/2014 (SR), MRP-MAJOR-ELEC-2013-27085 dated on 29 Dec 2015 entitled **"Studies on Fuzzy Logic Thermal Compensation Technique for High Speed Precision Machine"** by **Dr. Mudholkar Ravindra Ramchandra,** Department of Electronics has been assessed by the committee consisting the following members for final submission of the report to the UGC, New Delhi under the scheme of Major Research Project.

Comments/Suggestions of the Expert Committee:-

The Major Research Project entitled *"Studies on Fuzzy Logic Thermal Compensation Technique for High Speed Precision Machine"* by *Dr. Mudholkar Ravindra Ramchandra,* Department of Electronics has been successfully implemented w.r.t. all objectives. An experimental setup for Machine Tool Spindle Unit Assembly is being designed that is interfaced to the motor drive assembly, Thermoelectric Cooler Module and Sensor System via FPGA Board. For compensating the spindle temperature, a Fuzzy Logic Controller designed is implemented in FPGA. Study of temperature response of spindle system is made for rpm up to 5000, and temperature compensation by Fuzzy Logic Controller is studied with spindle running at 1000 rpm. The simulated and real time response of spindle temperature compensation are presented. The overall implementation of research project is good and it can be taken up to the industrial scale. Detailed report of work-done is also prepared. The research outcome has been published in three reviewed Journals and one paper is presented in international conference.

Name & Signatures of Experts with Date:-

Name of Expert	University/College name	Signature with Date
1. Dr. J. S. Kadadevrmath	Professor Karnatak University, Dharwad	*kpoodish* 11/1/19
2. Dr. M. P. Ghatule	Professor & Principal, Sinhgad Institute's Sinhgad College of Science, Pune	11/1/2019

It is certified that the final report has been uploaded on UGC-MRP portal on ....

It is also certified that final report, Executive summary of the report, Research documents, monograph academic papers provided under Major Research Project have been posted on the website of the University/College.

Registrar

Registrar
Shivaji University, Kolhapur