File Number : ECR/2016/000760

Project Title : Design and Development of Three Axis Flexural Stages for Micro-Milling Workstation

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Introduction:

Microstructures such as microchannels are required in various applications such as in microfluidic lab on chip device (biomedical tests), medical devices, and so on. Laser based micromachining and lithography processes are widely used in development of such microchannels. These processes have shown capability to develop such microchannels with good accuracy and resolution. However, the initial cost of the fabrication is very high due to employment of laser unit. Hence development of low cost solution of micromilling work station is needed. This project presents the design and development of flexural guide way based micromilling work station. A flexure based system allows motion by bending the load elements. These are very simple to manufacture, light in weight, possess very low friction, no lubrication and hysteresis. Due to these advantages flexural based mechanisms and bearings are used in laser scanner in compact disc, microstereolithography and for linear compressor of cryocooler and so on.

Approved Objectives of the Project

1: Design and development of double flexural XY stage

2: Design and development of spiral shaped flexural Z-stage

3: System integration for the development of micro-milling workstation

4: Characterization of dynamics of the flexural stage based micro-milling workstation

5: Fabrication of complex shaped microstructures using developed micro-milling workstation

Executive summary of the Project:

This project presents implementation of flexural stages in design and development of three axis micromilling workstation. In this project micromilling workstation, XY motion will be imparted to the work piece and Z –motion will be provided to the stage holding milling cutter. The double flexural mechanism stage will be developed for the linear XY motion. For machining operation, milling torque will be achieved with the help of brushless DC motor. To monitor and control the entire process in real time, the system will be built with encoders, data acquisition system and controller. Based on the data acquired the controlling action will be taken and provided to the concern actuator. Due to inherent characteristics of the flexural mechanisms, this system is expected to execute milling of complex shape geometry with high accuracy. The concept of implementation of flexural system is expected to open new avenue in several other applications in micromachining.

Brief Methodology

a. *Design and development of double flexural XY stage*

Figure 1 (a) shows a double flexural mechanism (DFM) for one of the XY stage. Design of XY flexural stage mainly involves determination geometrical parameters of flexible links. These are designed considering static and dynamic forces acting on the primary motion stage.

b. *Design and development of spiral shaped flexural Z-stage*

In flexural Z-stage, assembly consists of two sets of parallel stacked flexure discs interspersed with central and peripheral spacing rings (see Figures 1(b), (c) and -2)[1-3].

c. *System integration:*

The appropriate actuators and sensors will be embedded for actuation of stages and purpose of position sensing for feedback respectively. Figure 3 shows the schematic representation of system integration for micro-milling workstation.

d. *Characterization of dynamics of the flexural stage:*

The effect of different parameters of the flexural discs is observed for displacement, radial and axial stiffness. The results are presented in the non-dimensional form for its generalization (see Figure 4). In analysis (z/d), (s/d), (p/d) and (t/d) are dimensionless axial displacement, spacing, spiral pitch and flexural plate thickness respectively (refer Figure 1(b), 2(a) and 4 (a))[2-4].

e. *Fabrication of complex shaped microstructures:*

System will be used to fabricate the complex shaped microstructures.

Innovative approaches adopted in executing the project (Five to ten points)

1. A flexure based system is used to fabricate various complex geometry microstructures.
2. The non-dimensional characterization of the flexural mechanism
3. Generalized design methodology for two stage three arm spiral shaped flexural system
4. Frictionless high accuracy linear guide ways
5. Low power consumption micro-milling workstation
6. High speed high torque micro-milling workstation.
7. Exhaustive synthesis of the developed system to develop process plan for design of flexural based systems for linear guidance in micromachining

Results / Figures / Tables & Photographs

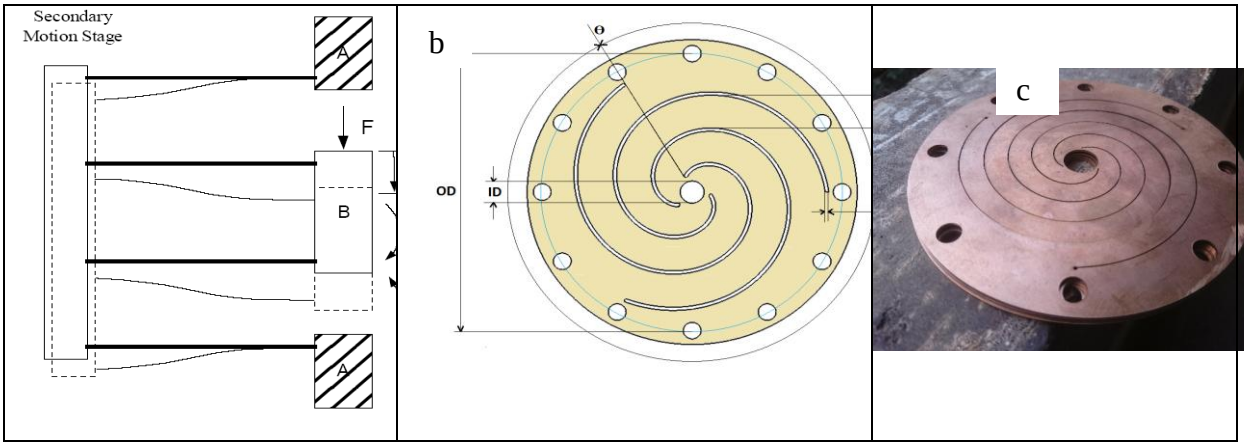

Figure 1: (a) Double parallelogram flexural system for XY stage (b) CAD model of 3 arm flexural disc; (c) fabricated spiral shaped flexural disc to form flexural feed stage [1-3].

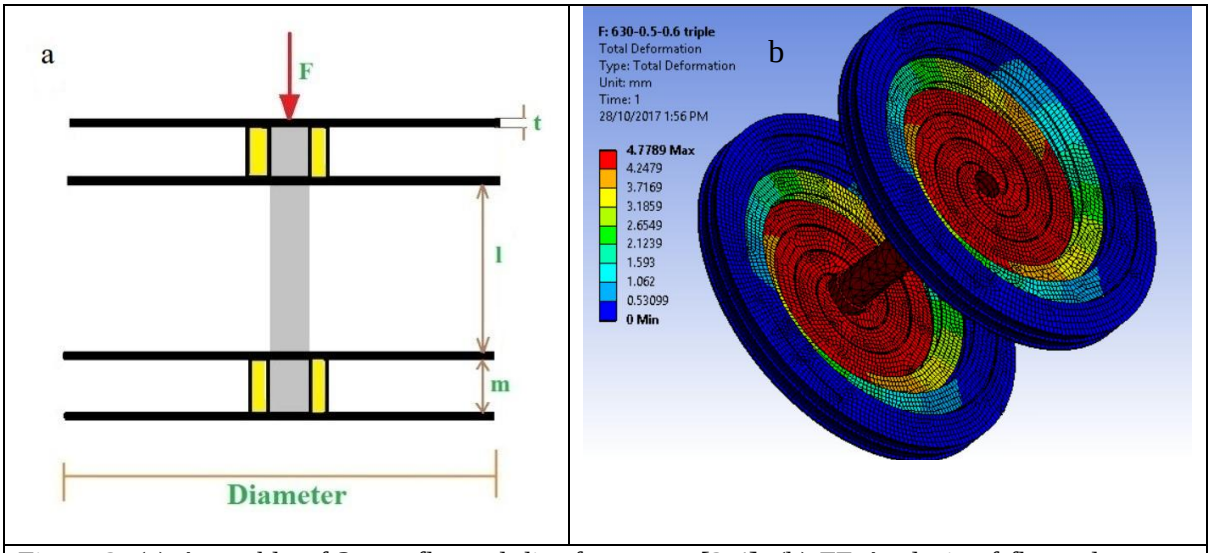

Figure 2: (a) Assembly of 3 arm flexural disc for z-stage[2-4]; (b) FE Analysis of flexural z-stage [1]

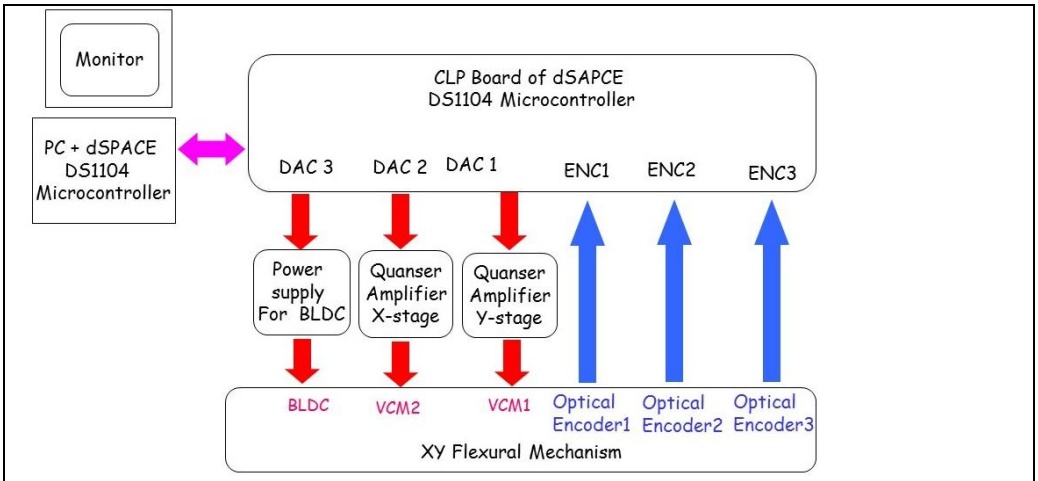

Figure 3: System integration for micro-milling workstation

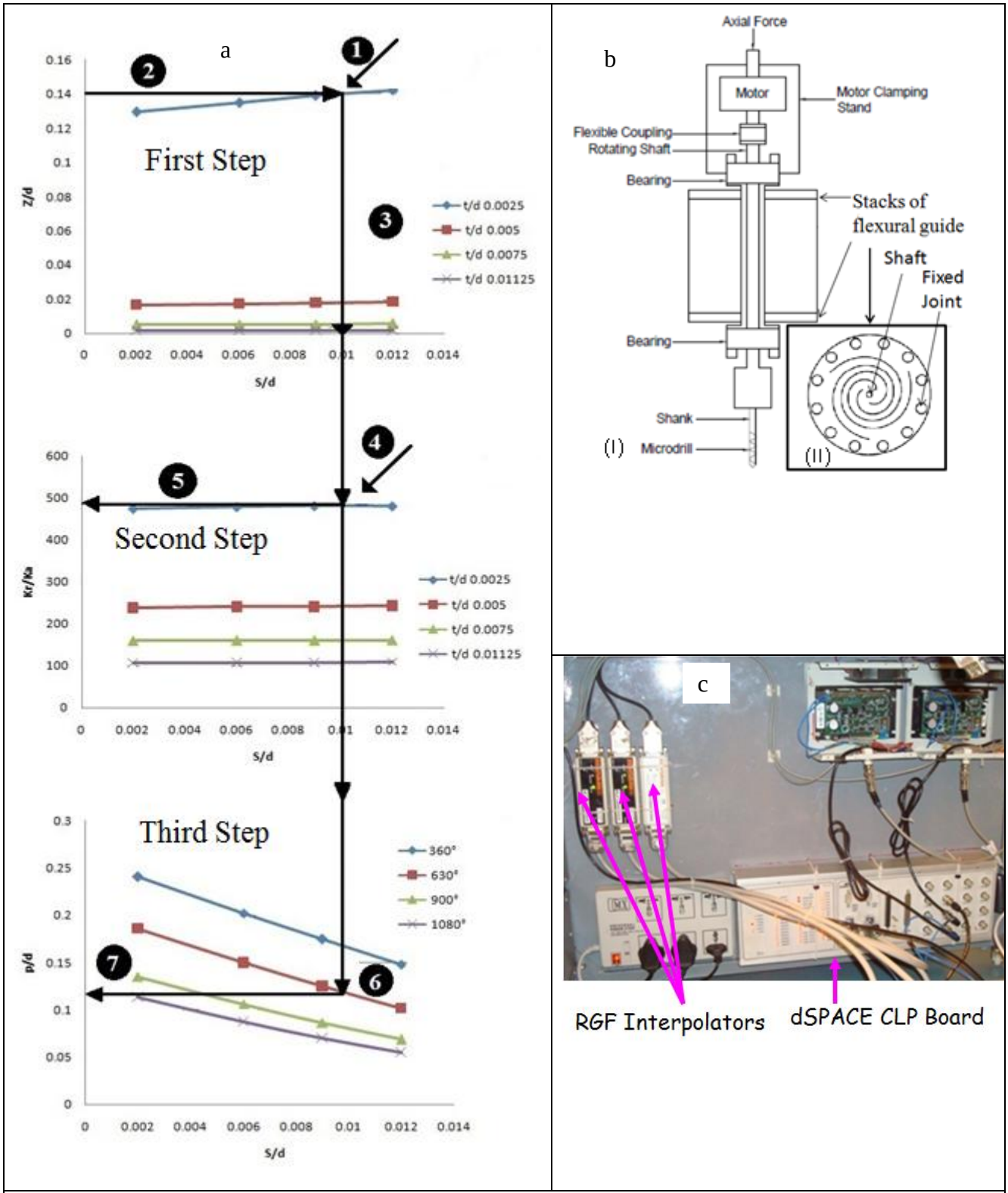

Figure 4. (a) Design method example for two layer three arm flexure system with Z/d=0.14 [2-4](b) Schematic of flexural z-stage of micro-milling (c) RGF interpolators of encoders and dSPACE 1104 DAQ platform.

Research highlight of this project (five to ten points)

1. Ph.D Produced No: 01 (in progress)
2. Technical Personnel Trained = 08
3. Research Publications arising out of the present project: 04
4. Low cost micro-milling workstation
5. Portable micro-milling workstation

Outcomes, Salient points, break through promising technology etc., emanated Out of this project: (five to ten points)

1. Low cost solution for micro-milling especially in job or batch production applications where in the laser based systems are not viable

2. The project will be used as an effective alternative way for the fabrication of various complex geometry microstructures.

3. Micro-milling station with portability

4. The developed system can be readily useful for the fabrication of complex shape microchannels for various clinical and chemical tests.

5. Ease of fabrication and lesser cost of production without compromising accuracy and resolution.

6. Based on similar concept, flexure based mechanisms can also be used in high and ultra-high precision devices, e.g. robots and manipulators, ultra-high turning, grinding, operations and also in ultra-clean environments, high and ultra-high vacuum system.

7. Also such mechanism can find the applications in the space instruments that can be installed in satellites which require longer life approximately more than five years

8. The project has potential to have patent on utility of flexural stages for micro-milling and product development for its utility in the manufacturing society.

National & International importance of this project:

Micro-milling is one of the emerging fabrication technologies. It is characterize by mechanical interaction of sharp tool and workpiece, causing breakage of workpiece material along defined path and eventually removing unwanted useless part from the workpiece. With conventional milling process it is not possible to obtain feature as small as in lithographic processes. Although small features are possible with lithography processes, it is not possible to fulfil the demand for generation of complex shaped micro-features in various applications such as mask for deep x-ray lithography, asymmetric high precision molds for micro-channels, defence parts etc which are built in high strength materials. Further in most popular laser based machining processes these complex microstructures are quite possible. However,

these involve huge initial cost. This has motivated for the development of micro-milling process. The flexural based stages [1-15] which have proved its capability to provide high resolution in scanning is proposed in the conventional milling process. Inherent accuracy in linear motion of the flexural guideways would be able to make micro-milling with ease and in economical way. Thus the deployment of the flexural system is expected to provide low cost solution for the development of highly accurate micro-milling workstation. The proposed utility of the flexural mechanism in micro-milling centre is expected to open new avenue in the development of the other micro-machining centres such as micro turning centre [5], micro grinder [6] and so on. Further the proposed project aims in the synthesis of the mechanism in non-dimensional way. The non-dimensional characterization of the flexural mechanism will lay the design guidelines for the design of several other flexural based systems.

Technology Transfer (if any): Nil

National List of SCI journal Publications from this Project (format given): Nil

Inter-National List of SCI journal Publications from this Project : Nil

Papers published in Conference Proceedings : 04

1. Kiran Bhole and Megha Janbandhu, Design and Development of Double Spiral Shaped Flexural Feed Stage for Micro-drilling Workstation, International Conference on Advances in Materials and Manufacturing Applications IConAMMA 2017, 17th -19th August 2017.
2. Kiran Bhole and Vinit Sonavane, Parameter Based Method for Three Arm Spiral Shaped Flexural Bearing, International Conference on Materials Processing and characterization, Hyderabad, Materials Today Proceedings, 5 (2018) pp 19380-19390.
3. Vinit Sonavane and Kiran Bhole, Frequency Analysis of Two Stage Three Arm Spiral Shape Flexural Bearing, 2nd International Conference on Frontiers in Engineering, Applied Sciences and Technology, NIT Tiruchirappalli, 2018.
4. Kiran Bhole and Vinit Sonavane, Static and Frequency Analysis of Triple Stage Three Arm Spiral Shape Flexural Bearing using FEA, International Conference on Advances in Materials and Manufacturing Applications IConAMMA 2018, 16th - 18th August 2018.

Patents filed/ to be filed: Nil

Research Area / Area of Interest (Key points)

Micro-machining, Micro-fabrication, Flexural systems, Lithography, Compliant Mechanisms.

Reference citations

[1] Kiran Bhole and Megha Janbandhu, Design and Development of Double Spiral Shaped Flexural Feed Stage for Micro-drilling Workstation, International Conference on Advances in Materials and Manufacturing Applications IConAMMA 2017, 17th -19th August 2017.

[2] Kiran Bhole and Vinit Sonavane, Parameter Based Method for Three Arm Spiral Shaped Flexural Bearing, International Conference on Materials Processing and characterization, Hyderabad, Materials Today Proceedings, 5 (2018) pp 19380-19390.

[3] Vinit Sonavane and Kiran Bhole, Frequency Analysis of Two Stage Three Arm Spiral Shape Flexural Bearing, 2nd International Conference on Frontiers in Engineering, Applied Sciences and Technology, NIT Tiruchirappalli.

[4] Kiran Bhole and Vinit Sonavane, Static and Frequency Analysis of Triple Stage Three Arm Spiral Shape Flexural Bearing using FEA, International Conference on Advances in Materials and Manufacturing Applications IConAMMA 2018, 16th -18th August 2018.

[5] Y. Tian, B. Shirinzadeh and D. Zhang, A flexure-based mechanism and control methodology for ultra-precision turning operation, Precision Engineering, 33 (2009) 160-166.

[6] Y. Tian, D. Zhang and B. Shirinzadeh, Dynamic modelling of a flexural mechanism for ultra-precision grinding operation, Precision Engineering, 35 (2011) 554-565.

[7] N.Chen, X. Chen, Y.N.Wu, C.G. Yang, Spiral profile design and parameters analysis of flexure bearing, Cryogenics, 46 (2006) 409-419

[8] Lee C. C, Pan RB. Flexure bearing analysis procedures and design charts. Cryocoolers, vol. 9. New York: Plenum Press; 1997. p. 413– 20.

[9] Trollier T, Ravex A, Mullie J, High capacity flexure bearing Stirling cryocooler on-board the ISS. Cryocoolers, vol. 12. New York: Plenum Press; 2003. pp. 31–35.

[10] Rawlings Richard M, Miskimins Scott M. Flexure springs applied to low-cost linear drive cryocoolers, Proceedings of SPIE. Infrared technology and applications XXVI, vol. 4130. SPIE; 2000. p. 406–12.

[11] C. J. Simcock, Investigation of materials for long life, high reliability flexure bearing springs for Stirling Cryocoolers applications, Cryocoolers 14 (2007).

[12] Yingxia Qi, Yinong Wu, Hua Zhang and Xi Chen, Simulation of deformation of diaphragm spring grooved with spiral slits by FE method, DETC2009-86371, ASME 2009 International Conference, IDETC/CIE 2009.

[13] Jung-Jae Kim, Young-Man Choi, Dahoon Ahn, Beomseok Hwang, Dae-Gab Gweon, Jaehwa Jeong, A millimeter-range flexure-based nano-positioning stage using a self-guided displacement amplification mechanism, Mechanism and Machine Theory, Volume 50, April 2012, Pages 109–120.

[14] J. B. Hopkins, M. L. Culpepper, Synthesis of Precision Serial Flexure Systems Using Freedom and Constraint Topologies (FACT), Precision Engineering, 2011, 35(4): pp. 638-649.

[15] R.M. Panas, J. B. Hopkins, Eliminating Underconstraint in Double Parallelogram Flexure Mechanisms, Journal of Mechanical Design, 2015, 137(9): 092301.

Feedback of this Scheme:

1. **How Young Scientist Scheme is important in your Research Activity or R&D carrier?**

   The Young Scientist Scheme helps in research activity or R&D carrier in following ways:

   1. scheme provides and enhances involvement of young aspirants in the field of research.

   2. scheme provides opportunities for executing exciting and innovative research ideas through its generous funding.

   3. scheme provides opportunity to extend research areas to its new level.

   4. scheme enables setting up research facility in the institute.

   5. scheme also enables technical training to aspirants.

   6. scheme gives opportunity to share /exchange knowledge at the national level in the field of science and technology.

2. **Present status of Academic and Industrial Research activities.**

   1. Ideally, the research institutions are recognise as a source of new ideas and industry offered a way to maximising the use of these ideas.
   2. Industrial research is more towards the application and product development.
   3. In recent years there is a significant collaboration between both parties.

   Research gap between Industry and Academic.

   1. Both Academics and Industrialists have different approaches.
   2. Industry prefers proven solutions with a low risk. Academia is interested in creating new solutions but lacks in its reach to society. Hence both parties are needed to start working for solution to a common problems

3. **Next twenty-year Research activities towards your specific area.**

   The area of micro-manufacturing is expected to get drastic changes in future due to thriving technologies such as Internet of Things (IoT), embedded systems, smart sensors, CAD and so on. Due to these technologies of interdisciplinary nature, the processing systems are expected to get new dimensions. May be in few years micro-machining could be performed remotely due to IoT enabled systems. Further coupling CAD system with the processes will make process fast and easy for user.

4. **More information (If require): ---**