Government of India
Department of Science & Technology
Technology Bhawan, New Mehrauli Road,
New Delhi-110 016

(**The Investigator is requested to fill the project title below and address on the reverse**)

ACKNOWLEDGEMENT CARD

Acknowledged with thanks the receipt of ______copies of your research proposal entitles_________
____
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____

(For SERC Division)
Name:_____________________
Designation:_____________________
Date:____________
(Please detach and send along with the proposal. No postal stamp is required)

REVERSE SIDE:
Your DST reference No:_________ /SERC/__________
(For any query quote this number)

To
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PIN____________

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Endorsement from the Head of Institution*
(To be given on letter head)

Project Title: *Study and Analyses of Light Weight, High Speed Robot Arms*

1. Certified that the Institute welcomes participation of **Dr. S.K. Saha** as the Principal Investigator and **Dr. S.P. Singh** as the Principal Co-Investigator for the project and that in the unforeseen event of discontinuance by the Principal Investigator, the Principal Co-Investigator will assume the responsibility of the fruitful completion of the project (with due information to DST) .

2. Certified that the equipment and other basic facilities as enumerated in Section 420 and such other administrative facilities as per terms and conditions of the grant, will be extended to the investigator(s) throughout the duration of the project.

3. Institute assumes to undertake the financial and other management responsibilities of the project.

Date: 24/9/02 **Name and Signature of Head of Institution**

Place: New Delhi

NB : In regard to the research proposals emanating from scientific institutions/laboratories under various scientific departments, the Head of institution is required to provide a justification indicating clearly whether the research proposal falls in line with the normal research activities of the institution or not and if not, the scientific reasons which merit its consideration by DST .

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Certificate from the Investigator

Project Title: *Study and Analyses of Light Weight, High Speed Robot Arms*

1. I/ We agree to abide by the terms and conditions of the SERC research grant.
2. I/ We did not submit the project proposal elsewhere for financial support.
3. I/ We have explored and ensured that equipment and basic facilities (enumerated in Section 420) will actually be available as and when required for the purpose of the projects. I/We shall not request financial support under this project, for procurement of these items.
4. I/ We undertake that spare time on permanent equipment (listed in Section 350) will be made available to other users.
5. I/We have enclosed the following materials:

Items	**Number of copies**
a) Endorsement from the Head of Institution (on letter head)	One
b) Certificate from Investigator(s)	One
c) Details of the proposal from Section 101 to 500 (stitched) + one soft copy on 3 1/2" floppy, preferably in MS Word m Investigator(s)	**20 / 10 for IRPHA**
d) Name and address of experts/institution interested in the subject/outcome of the project.	One
e) Sheet containing sections 101 to 192	One
f) Cover sheet by the Investigator	One

Date:
Place:

Name and signature of Principal Investigator (**Dr. S.K. Saha**)

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Names and Address of Experts

Prof. T. Nagarajan
Dept. of Mechanical Engineering
IIT, Madras, Chennai-600 036

Prof. Amalendu Mukherjee
Director, I.I.T., Kharagpur
Kharagpur-721 302, West Bengal

Prof. Mruthujaya/Dr. Ashitava Ghosal
Dept. of Mechanical Engineering
IISc, Bangalore-560 012

Prof. Amitabha Ghosh/Prof. Ashok Mallik
Dept. of Mechanical Engineering
IIT, Kanpur-208 016

Prof. C. Amarnath/Prof. Bharat Seth
Dept. of Mechanical Engineering
IIT, Bombay
Powai, Mumbai-400 076

Names of Institutes Interested in the Subject

All IITs; ISRO (Bangalore, Tiruvanantapuram); BARC (Mumbai);
IGCAR (Kalpakkam).

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Study and Analyses of Light Weight, High Speed Robot Arms

A project submitted to the Department of Science and Technology, Government of India, New Delhi

by

Dr. S. K. Saha
Dr. S. P. Singh

Department of Mechanical Engineering
Indian Institute of Technology, Delhi
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September 25, 2002

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**FORMATS FOR SUBMISSION OF PROJECTS
(To be filled by applicant)
{Sections 101 to 192 to be on separate sheet(s)}**

101. Project Title: *Study and Analyses of Light Weight, High Speed Robot Arms*

102. Broad Subject: Engineering Sciences

103. Sub Area: Robotics and Manufacturing

104. Duration in months: 36months

105. Total cost: 19.0 lakhs

106. FE Component: NIL

107. Project Category: Basic Research

111. Principal Inv.: Dr. S.K. Saha

112. Designation: Associate Professor

113. Department: Mechanical Engineering

114. Institute Name: IIT Delhi

115. Address: Hauz Khas, New Delhi 110 016

116. Date of Birth: Sept. 02, 1961**; Sex (M/F):** M

117. Telephone Fax Gram e-mail: Tel (011)659 1135; Fax: 685 7753; Email: saha@mech.iitd.ac.in

118. Co-Investigator: Dr. S.P. Singh

119. Designation: Associate Professor

120. Department: Mechanical Engineering

121. Institute Name: IIT Delhi

122. Address: Hauz Khas, New Delhi 110 016

123. Date of Birth: Jan. 20, 1968; **Sex (M/F):** M

**This is a sample proposal to DST, Govt. of India.
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124. Telephone Fax Gram e-mail: Tel (011)659 1136; Fax: 685 7753; Email: singhsp@mech.iitd.ac.in

Project Title: *Study and Analyses of Light Weight, High Speed Robot Arms*

Registration No..........................(to be filled by DST)

Principal Investigator........................Institution

I) Dr. S.K. Saha.................................... IIT Delhi

II) Dr. S.P. Singh (Co-PI)...................... IIT Delhi,

191. Project summary (maximum 150 words)

The demand for faster, high payload capacity, energy efficient robot arms are increasing day by day. Since present industrial robot manipulators are made of rigid links whose weight to payload capacity ratio is high they cannot be used in high speed applications. Hence, the robot links should be made of low weight to payload capacity ratio. Such robot links can provide higher speed but they start vibrating. As a result, inaccuracies crop in. If their dynamics are studied properly, these inaccuracies can be controlled using a suitable control algorithm. Besides, the robot arms can be made of composite materials like Fiber Reinforced Composites (FRC), whose strength to weight ratio is high compared to the conventional materials like steel or aluminium.

In this project, a dynamic model for a serial-chain robot arm made of flexible links will be developed. Recursive algorithms based on the dynamic modeling using the Decoupled Natural Orthogonal Complement (DeNOC) matrices which was proposed by the principal investigator and applied successfully to *rigid* serial- (Saha, 1997; 1999a,b) and parallel-chain (Saha and Schiehlen, 2001) robot manipulators will be extended to *flexible* serial-chain robot arms. Besides, FRC will be examined as an alternative robot link material. Some preliminary work on FRC as robot link has been carried by the investigators (Mathan, et al, 1999; Singh, 2001). A two-link AC servo controlled robot arm will be fabricated to verify the simulation results. During the experiments, both conventional (say, aluminium) and FRC materials will be considered as robot links.

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192. Key words (maximum 6): Serial, Flexible, FRC, Dynamics, Simulation, Experiment.

200. Technical details

210. Introduction (under the following heads)

Traditionally, robot manipulators are made of rigid links, i.e., their weight to payload ratio is very high. This is believed to be necessary for accuracy and repeatability. However, it leads to higher material cost and increased energy consumption. Higher robot speeds can be achieved using lighter links in which case length to cross-section area ratio of the robot links has to be increased leading to elastic deformations during the manipulator operations. Such robot arms are termed as `flexible,' which has low weight to payload capacity ratio. These deformations degrade the path-tracking performance of the end-effector. In order to improve their performance, it is necessary to compensate for these deflections by knowing their magnitude and direction through a suitable dynamic model. Alternatively, advanced materials like Fiber Reinforced Composites (FRC) having higher strength to weight ratio can be used to achieve high speed. Light weight high speed robot arms are quite attractive for space structure applications, e.g., as space robots, solar panel supports, and others. Thus, in this project, the following activities will be taken up:

1. Development of a dynamic model for a serial flexible robot arm;
2. Simulation algorithm for the flexible arm using the Decoupled Natural Orthogonal Complement (DeNOC) matrices that was proposed by the principal investigator and successfully applied to the rigid serial- (Saha, 1997; 1999a,b) and parallel-chain (Saha and Schiehlen, 2001) systems;
3. Fabrication of servo controlled two-link flexible arm using conventional material like aluminium;
4. Experimental verification of the simulation results;
5. Dynamic analysis of FRC robot arm using
    - rigid body algorithm developed in an earlier DST sponsored project (Saha, 1999a)
    - flexible body algorithm to be developed in this project

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7. Using the above experimental setup, verify the simulation results of the FRC robot arms.

It is envisaged that the industries like, Indian Space Research Organization (ISRO), Bangalore, the Indira Gandhi Centre for Atomic Research (IGCAR), Kalpakkam, and private companies with fast assembly lines such as in TIMEX Watches, SAMTEL Colour Tubes, and others, may be interested with the proposed research results. ISRO has already begun research in the area of space robotics (Gupta, et. al., 1995), and IGCAR requires systems for the handling of control rods for their Fast Breeder Reactors (FBR) (IGCAR Pamphlet, 1995).

211. Origin of the proposal

The requirement of higher productivity has led to increased operating speeds for most industrial machinery, and the adaptability of a robotic arm can significantly influence the overall performance of the system. Comprehensive work has been published for the dynamic modelling of mechanical arms in which rigid links are assumed. Such an assumption limits the use of the mechanism in high speed, high payload capacity applications. The deficiency has motivated researchers to investigate the problems that result from the assumption of the flexible structure, e.g., in Cyril (1988), Theodore and Ghosal (1995), Shabana (1997), Gamarra-Rosado and Yuhara (1999), Ider, et al (2002) and others.

On the other hand, there is a considerable interest in the development of *recursive* forward dynamics algorithm required for computer simulation of robot arms (Featherstone, 1983; Rodriguez and Kreutz-Delgado, 1992; Saha, 1997; 1999a,b). Whereas the conventional forward dynamics programs for robot arms with rigid links require computations of order n^3, i.e., $O(n^3)$ (Walker and Orin, 1982; Angeles and Ma, 1988),---n being the number of links in a serial-chain robot---recursive algorithms need $O(n)$ calculations. The recursive algorithms are also known to be numerically stable (Cloutier, et al, 1995).

The recent successful application of the recursive forward dynamics algorithm for the rigid serial-chain robot manipulators (Saha, 1997; 1999a,b) to the parallel-chain (Saha and Schiehlen, 2001) manipulators has inspired the investigators to apply the recursive methodology to *flexible* systems as well. Furthermore, researchers are

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exploring composite materials as an alternative link materials for high speed robot applications, e.g., Sung and Shyl (1990) and Singh (2001). Some preliminary work in this direction by the investigators (Mathan, et al, 1999; Singh 2001) has inspired the team to investigate whether they can be treated as *rigid* or *flexible* in order to use them robot link materials, and also verify the results experimentally.

212. Definition of the problem

The primary problem is to investigate the applicability and efficiency of the recursive dynamics algorithm of Saha (1997, 1999a,b) for the dynamic simulation of flexible arms. The algorithm is developed for serial rigid-body robot arms and has slightly better efficiency (Saha, 1999b) than similar algorithms, e.g., with that of Featherstone (1983). The method is also different, which, in the investigators' opinion, is easy to grasp. The method is based on the linear algebra theory, namely, the Gaussian elimination of the symmetric positive definite inertia matrix, which is obtained from the fundamental Newton-Euler equations of motion and using the Decoupled Natural Orthogonal Complement (DeNOC) matrices (Saha, 1999a,b). Alternatively, the approach of Featherstone (1983) is based on the `articulated-body inertia' matrix that relates a spatial force applied to a particular member of an articulated body to the spatial acceleration of that member by taking into account the effect of the rest of the articulated body. The method of Rodriguez and Kreutz-Delgado (1992) uses Kalman filtering and smoothing techniques appearing in Control theory. Note that the application of the DeNOC to parallel structures, e.g., Stewart Platform, has led to the *recursive, minimum-order, ODE (ordinary differential equation),* dynamic formulation, which was not available earlier than Saha and Schihelen (2001).

The proposed computer simulation algorithm for the flexible arm manipulator will be tested with a 2-link experimental flexible arm. The flexible links will be independently controlled by two servomotors. The arm will be instructed to follow a given path. Actual path will be sensed through sensors, say, joint encoders, for the comparison of the simulation results. This comparison is important to judge the effectiveness of the proposed forward dynamics algorithm to be developed in this project. Moreover, it will help to design a controller to reduce the end-effector vibration. In order to achieve the high

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speed, Fiber Composite Reinforces (FRC) links will be considered as an alternative link material. The FRC will be modelled both as rigid and flexible. Experiments are also planned with FRC links.

213. Objective

1. Dynamic modelling of a two-link serial flexible arm;
2. Development of computer algorithms for simulation of a two-link flexible arm;
3. Fabrication of a 2-link flexible arm (say, using aluminium with high length to cross-section ratio) with servo motors;
4. Study the behaviour of the real arm and compare with the simulation results obtained from the algorithm developed in Step 2.
5. Study of a robot arm made with Fiber Reinforced Composite (FRC). The FRC links will be treated both as rigid and flexible;
6. Experimental verification of simulation results for the FRC links.

220. Review of status of Research and Development in the subject

221. International status

Research on robot arms with flexible arms and its control has started in the international arena since early 1970s (Ness and Farenkopf, 1971). Both theoretical and experimental are reported in the literature. Some of the work in the last decade is summerized below:

- *Cyril (1988), McGill University, Canada*: In this Ph.D work, a general method for the formulation of the dynamical equations of general *n*-axis, serial-type robotic manipulators of otherwise arbitrary architecture, with *f* flexible and *r* rigid links, i.e., $n=f+r$, is presented. Two different methods of formulations, namely, Newton-Euler and hybrid Newton-Euler/Euler-Lagrange, are discussed. The latter is found to be systematic and conceptually straightforward for flexible arms. A simulation package, FLEXLINK, is developed using the conventional forward dynamics algorithm. No experimental verification was carried out.

- *Yuh, et. al. (1989), Univ. of Hawaii, USA*: Dynamic model of a flexible link having rotational and translational motion is derived using the Lagrangian equations. The validity of this model was investigated by comparing the results of the computer simulation.

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- *Wang and Vidyasagar (1989, 1992), Univ. of Waterloo, Canada*: In the paper of 1989, some issues in the transfer function modelling of a single flexible link are examined. It was shown that when the number of modes is increased for more accurate modelling, the relative degree of the transfer function becomes ill-defined, which greatly affects the performance of the controller. An alternate approach was proposed. In the latter paper (1992), design related problem of a passive controller was discussed.

- *Book (1990), Georgia Institute of Tech., USA*: It summarized the contemporary works on flexible arms.

- *Yoshikawa and Hosoda, (1996), Japan*: A dynamic model was developed using virtual rigid links and passive joints. The simulation results were compared with 2-link experimental set-up. Later, a PD controller was used to stabilize the vibration.

- *Aoustin and Formal'sky (1997), Ecole Centrale de Nantes, France*: A near-optimal trajectory is designed for a flexible one-link manipulator, which is verified by an experimental set-up.
- *Ider et al (2002), Middle East Technical Univ., Turkey*: A control algorithm is proposed here based on the linearized dynamic model of a robot made with flexible links. The control is claimed to be stabilized while tracking a path accurately.

222. National status

In India, a variety of robotic research has been conducted, starting from typical industrial robot to advanced level mobile robots (both wheeled and walking types), teleoperation, underwater robots, etc., in various research institutes like Bhabha Atomic Research Center, Mumbai; Centre for Artificial Intelligence and Robotics, Central Manufacturing Technology Institute, and Indian Institute of Science (IISc), Bangalore; Indian Institutes of Technology (IITs), Bombay, Delhi, Kanpur, Kharagpur, and Madras; Jadavpur University, Calcutta, and others. Comprehensive description of these activities can be obtained in the DST Proceedings (1988), DSIR Report (1992), and NIE Proceedings (1996). Related to the flexible body modelling of robot arms, following contributions are traced in the national level:

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- *Gandhi, et. al. (1993), IIT, Delhi*: In this work a study of dynamic behaviour of a (R-R) nonplanar flexible manipulator subjected to a prescribed motion has been carried out. The dynamic equations of motion were derived from Hamilton's principle.

- *Ravi Sankar, et. al. (1995), IIT, Madras*: This paper presents a finite element method to calculate the end-effector deflection and actuator torques for the light weight flexible manipulators made up of composite materials.

- *Theodore and Ghosal (1995), IISc, Bangalore*: Comparison of two discretization techniques of flexible arms, namely, Assumed Mode and FEM, were done, where Lagrangian formulation was used for dynamic equations of motion. The results were illustrated by numerical simulation of a RRP configuration robot.

- *Bangara Babu and Nagarajan (1997), IIT, Madras*: This work deals with the effect of joint velocities on the dynamic performance of flexible manipulators. The dynamic equations of motion were derived from the Lagrangian principle. Simulation of a 3-link spatial manipulator was presented.

- *Thomas and Bandyopadhyay (1997), IIT, Bombay*: A controller is designed for the tip position control of a single-link flexible arm. The controller was shown to be robust to parameter variations and disturbances.

- *Mathan, Saha, and Singh (1998), IIT Delhi*: In this work, flexible body modelling is proposed, where conventional material like steel and aluminium and the advanced material like Fiber Reinforced Composite (FRC) are modelled as a flexible links. Their behaviours are compared and suitability of the FRC is established for high speed robot applications.

- *Singh (2001)*: In this work, aluminium and FRC links are compared for the workspace, accuracy, and repeatability of the stepper motor drived HaPRA (Hanging Planar Robotic Arm) robot developed at IIT Delhi.

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Note that none of the above has carried out any experimental verification of the link vibrations. Moreover, the proposed project stands out mainly in the following ways:

1. Extension of a new recursive simulation technique (Saha, 1997; 1999a,b) to flexible manipulators;
2. Experimental verification of the simulation results for a two-link flexible arm made of aluminium and FRC.

223. Importance of the proposed project in the context of current status

It is certain that light weight, high-payload capacity robot manipulators are very much desirable for high-speed operation and energy efficiency. These requirements demand that the robot links should be flexible. Hence, accurate dynamic models are required for the study of end-effector deflection through simulation. The verification of such model is important, as they will be essential for the design of a good controller and stabilization of the vibration. If the FRC performs better, the composite materials could be good substitute for the conventional materials, as they are easily and economically available these days.

224. Review of expertise available with proposed investigating group/institution in the subject of the project

Dr. S.K. Saha has done his Ph.D. on Multibody dynamics at McGill Univeristy, Canada, in 1991. His research at Toshiba Corporation, Japan, from 1991 to 1995 was on dynamics of of space robots, where he has developed its simulation software. Based on the Ph. D and Toshiba experiences, he has successfully developed two software RIDIM (Recursive Inverse Dynamics for Industrial Manipulator) and RFDSIM (Recursive Forward Dynamics and Simulation for Industrial

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Manipulator) in C++ as a part of his DST sponsored research project under the Scheme for Young Scientists. RIDIM is presently in use by the students of IIT Delhi for their Multibody Dynamics and Robotics courses. It is made freely available to other research/academic institutes (See www.angelfire.com/sc/saha). Besides, Dr. Saha has developed recursive dynamics algorithms for the parallel robotic structures (e.g., Stewart Platform) during his Humboldt Research (1999-2000) at the University of Stuttgart, Germany.

Dr. S.P. Singh has long been associated with the research in the area of vibration and control. He has significant contribution in carrying out several research projects on propeller shafts made of composites. His research work is focussed on design and development of composites for dynamic applications. His important research contributions include rotor-dynamic analysis of composite shafts, design of composite shaft for varied applications, design and development of composite crutch, damping predictions in composites. His current interests are in control and he has guided a number of research works in which useful algorithms for noise and vibration control have been developed and implemented. These include, efficient modal controller, Adaptive LMS controller for noise control, and fuzzy logic based controller for multi-modal control.

225. Patent details (domestic and international)

Key patents based on the worldwide patent search in the internet are as follows:

- <u>Related to robot links modelled as flexible bodies</u>

DE4133605 (Germany), "Flexible robot arm," by Fieten, W., Nov. 28, 1995.

US5,546,508 (United States), "Controlling flexible robot arms using high speed dynamics process," by Jain, A., Rodriguez, G., April 3, 1992.

US4,393,728 (United States) [Equivalent to JP56003193 (Japan), EP0017016 (Europe)], "Flexible arm, particularly a robot arm," by Larson, O., and Davidson, C., July 19, 1983.

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- Related to robot links made of composite materials

US6,431,019 (United States), "Low cost, high-strength robotic arm," by Greene, M.L., DeVane, S.J., and Tallman, J., Mar. 21, 2001.

US5,647,747 (United States), "Mechanized robots for use in instruction, training, and practice in the sport of ice and roller hockey," by Macri, V.J., Magaw, R.O., and Zilber, P., Jan. 20, 1995.

EP0576739 (Europe), "Welding gun," Gerbi, M., Jan. 05, 1994.

OTHER REFERENCES

Aoustin, Y., and Formal'sky, A., 1997, "On the synthesis of a nominal trajectory for control law of a one-link flexible arm," Int. J. Rob. Res., V. 16, N. 1, p. 36--46.

Angeles, J., and Ma, O., 1988, "Dynamic simulation of n-axis serial robotic mainpulators using a natural orthogonal complement," Int. J. Rob. Res., V. 7, N. 5, pp. 32--47.

Bangara Babu, P., and Nagarajan, T., 1997, "Effect of joint velocities on the dynamic performance of flexible robot manipulators," Proc. of the All Indian Manufacturing Technology Design and Research Conf., Jan. 9-11, Warangal, pp. 241--246.

Book, W.J., 1990, "Modeling, design, and control of flexible anipulator arms: A tutorial review," Proc. of the IEEE Conf. on Decision and Control, New York, pp. 500--506.

Cloutier, B.P., Pai, D.K., and Ascher, U.M., 1995, "The formulation stiffness of forward dynamics algorithms and applications for robot simulation," Proc. IEEE Conf. On R&A, Nagoya, Japan, May 21—27, V. 3, pp. 2816—2822.

Cyril, X., 1988, "Dynamics of Flexible-Link Manipulators," Ph.D. thesis, McGill University, Canada.

This is a sample proposal to DST, Govt. of India.
To be used as a guideline only.

DSIR Report, 1992, "Technology Status Study on Industrial Robots," A Report for the Dept. of Sc. & Ind. Res., (Min. of Sc. & Tech.), Divas Communications, New Delhi.

DST Proceedings, 1988, "Robotics," Proceedings of National Workshop, April 1987, Oxford & IBH Publishing Co. Pvt. Ltd., New Delhi.

CAIR Report, 1998, Workshop on the Current Status and Fugure Prospects of Indian Robotics (In honour of the 60th birthday of Mr. M.S. Ramakumar), May 27, CAIR, Bangalore.

Featherstone, R., 1983, "The calculation of robot dynamics using articulated-body inertia," Int. J. Rob. Res., V. 2, N. 1, pp. 13—30.

Gammara-Rosado, V.O., and Yuhara, E.A.O., 1999, "Dynamic modeling and simulation of a flexible robotic manipulator," Robotica, V. 17, pp. 523—528.

Gandhi, S.C., Gupta, K.N., and Pujara, K.K., 1993, "Dynamic analysis of a (R-R) flexible manipulator," Proc. of the CAD, CAM, Robotics and Autonomous Factories, Dec. 16-19, New Delhi, V. III, pp.149--159.

Gupta, R., Padmanabhan, K., Rathnakara, S.C., and Ganeshan, A.S., 1995, "Graphical Animation of Robot Arm for Space Applications," Proc. of the Int. Conf. on Automation, Dec. 12--14, Indore, India.

Ider, S.K., Ozgoren M.K. , and Ay V, 2002, "Trajectory tracking control of robots with flexible links," Mech. and Mach. Th., V. 37, pp. 1377-1394.

IGCAR Pamphlet, 1995, "Structural Analysis for FBR," by Structural Mechanics Section, Nuclear Systems Division, August.

Mathan, R., 1998, Analysis of Robot Manipulator Made of Feber Reinforced Composite, M. Tech Thesis, ME Dept., IIT Delhi.

Mathan, R., Saha, S.K., Singh, S.P., 1999, "Behaviour of robot links made of fiber reinforced composite material," Proc. of the Int. Symp. in Motion & Vibration Control in Mechatronics, Tokyo, Japan, Apr. 6-7.

This is a sample proposal to DST, Govt. of India.
To be used as a guideline only.

Nagarajan, T., Sivaprasad, N., and Ramachandran, S., 1988, "Finite element techniques in robots," Robotics (Proc. of the Nat. Workshop; April, 1987), Oxford & IBH Publishing Co. Ltd., New Delhi, pp. 91--95.

Ness, D.J., and Farenkopf, R.L., 1971, "Inductance methods for generating the dynamic equations of motion for multibodied flexible systems, Part 1: Unified approach, Synthesis of Vibrating Systems," ASME, New York, pp. 301--304.

NIE Proceedings, 1996, Proc. of the National Institute (NIE) of Engineering Golden Jubilee Nat. Symp. on R&A, Oct. 25-26, Mysore.

Ravi Sankar, N.V., Siva Prasad, N., and Nagarajan, T., 1995, "Finite element analysis of robot manipulators made of composite materials," Proc. of the Nat. Conf. on Machines and Mechanisms, Jan. 20-21, Durgapur, pp. B-31--B-37.

Rodriguez, G., and Kreutz-Delgado, K., 1992, "Spatial operator factorization and inversion of the manipulator mass matrix," IEEE Trans. on R&A, V. 8, N. 1, pp. 65—76.

Saha, S.K., 1997, "A decomposition of the manipulator inertia matrix," IEEE Trans. on R&A, V. 13, N. 2, Apr., pp. 301—304.

Saha, S.K., 1999a, Robot Design Using Dynamic Motion Study (HR/OY/E-02/96), Final report submitted to the DST sponsored project under Scheme for Young Scientists, May 1999.

Saha, S.K., 1999b, "Dynamic modelling of serial multi-body systems using the decoupled natural orthogonal complement matrices," ASME J. of Applied Mechanics, V. 66, Dec. pp. 986--996.

Saha S.K., and Schiehlen, W.O., 2001, "Recursive kinematics and dynamics for closed loop multibody systems," Int. J. of Mechanics of Structures and Machines, V. 29, N. 2, Aug., pp. 143-175.

Shabana, A.A., 1997, "Flexible multibody dynamics: Review of past and recent developments," Int. J. of Multibody System Dynamcs, V. 1, pp. 189-222.

Singh, S., 2001, Investigation of Robot Link Made of Composite Material, B. Tech Project Report, ME Dept., IIT Delhi.

Sung, C.K., and Shyl, S.S., 1990, "A composite laminated box-section beam design for obtaining elastodynamic responses of a flexible robot manipulator," Int. J. Mech. Sci, V. 32, N. 5, pp. 391—403.

Theodore, R.J., and Ghosal, A., 1995, "Comparison of the assumed modes and finite element models for flexible multilink manipulators," Int. J. of Rob. Res., V. 14, N.2, pp. 91--111.

Thomas, S., and Bandyopadhyay, B., 1997, "Position control of single link flexible manipulator by variable structure model following control," ASME J. Dyn. Sys., Meas., and Cont., V. 119, June, pp. 330—335.

Wang, D., and Vidyasagar, M., 1989, "Transfer functions for a single flexible link," Proc. of the IEEE Conf. on R&A}, Scottsdale, Arizona, May 14-19, V. 2, pp. 1042--1047.

Wang, D., and Vidyasagar, M., 1992, "Passive control of a stiff flexible link," Int. J. Rob. Res., V. 8, N. 1, pp. 572--578.

Walker, M.W., and Orin, D.E., 1982, "Efficient dynamic computer simulation of robotic mechanisms," ASME J. Dyn. Sys., Meas., and Cont., V. 15, N. 3, pp. 205—211.

Yoshikawa, T., and Hosoda, K., 1996, "Modeling of flexible manipulators using virtual rigid links and passive joints," Int. J. Rob. Res., V. 15, N. 3, pp. 290--299.

Yuh, J., Young, T., and Baek, Y.S., 1989, "Modeling of a flexible link having a prismatic joint in robot mechanism--Experimental verification," Proc. of the IEEE Conf. on R&A, Scottsdale, Arizona, May 14-19, V. 2, pp. 722--727.

230. Work plan

231. Methodology

This is a sample proposal to DST, Govt. of India.
To be used as a guideline only.

The methodology is outlined as follows:

1. *Literature survey*: The existing approaches to develop the dynamic model of a flexible link robot arm are:

- Euler-Lagrange (EL) equation and Assumed Mode Method (AMM);
- EL and Finite Element Method (FEM);
- Newton-Euler (NE) equation and AMM;
- NE and FEM.

In the above methods, AMM or FEM is used to discretize the flexible links, whereas the EL or NE equations describe dynamic equations of motion. NE method lends itself to very efficient recursive computations for dynamics of rigid-body manipulator. However, the NE recursions for complex systems like those containing flexible bodies are not directly applicable. On the other hand, the Euler-Lagrange (EL) method is conceptually much simpler, with the added advantage of not having to consider the internal forces and moments. However, straightforward implementation requires a great amount of lengthy partial differentiation, which also render these equations computationally less efficient that the other methods. In this project, a hybrid NE/EL (Cyril, 1988) will be used in which descretization will be carried out by both the AMM and FEM for comparison purpose.

2. *Simulation*: Having developed the dynamic equations of motion based on the methodology given in Cyril (1988), the recursive forward dynamics algorithm of Saha (1997, 1999a,b) will be used for simulation. The algorithm (Saha, 1999) is based on the application of the use of the Decoupled Natural Orthogonal Complement (DeNOC) and Gaussian Elimination (GE) rules to the expressions of the elements of the inertia matrix resulting from the dynamic equations of motion of the system at hand. This leads to the recursive expressions for the solution of the joint accelerations resulting an order *n* algorithm, i.e., $O(n)$. Commonly known approaches, e.g., Walker and Orin (1982), use the Cholesky decomposition [It is equivalent to GE of the symmetric positive definite inertia matrix.] of the inertia matrix whose elements are numbers. The latter gives rise to $O(n^3)$ algorithm because the recursiveness is not detectable. Both conventional material like aluminium and advanced material like Fiber Reinforced Composites will be considered as robot link materials.

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To be used as a guideline only.

3. *Experimental Set-up*: To verify the above simulation results, a 2-link 2-revolute jointed planar flexible arm will be built, which will be controlled by two independent servo motors.

4. *Study and Comparison*: Computer simulation and experimental results will be compared for the validation of the dynamic model and its forward dynamics algorithm.

232. Organisation of work elements

1. Discretization of a flexible link and the development of its dynamic model;
2. Kinematics study of the two-link serial flexible arm;
3. Write forward dynamics and simulation algorithm for the two-link flexible arm;
4. Use the algorithm of Step 3 to simulate;
5. Fabricate a prototype;
6. Carry out experiment and compare with computer simulation results.

233. Time schedule of activities giving milestones (also append to bar diagram and mark it as Section 410)

<u>0--12 months</u>:

- Literature survey
- Recruitment of Research Associate
- Analysis of a single-link flexible arm
- Upgradation of computing facilities
- Study and selection of composite materials
- Design of experimental setup

<u>13--24 months</u>:

- Recruitment of JRF

**This is a sample proposal to DST, Govt. of India.
To be used as a guideline only.**

- Analysis of two-link flexible arm
- Development of a simulation algorithm and obtain simulation results for the two-link arm to be built
- Procurement of the links, servo motors, and data acquisition systems for the two-link arm
- Fabrication of the two-link flexible arm.
- Testing of the experimental setup

<u>25--36 months</u>:

- Experiment with the two-link flexible arm when link material is (i) aluminium; and (ii) FRC
- Debugging
- Documentation

**This is a sample proposal to DST, Govt. of India.
To be used as a guideline only.**

234. Suggested plan of action for utilization of research outcome expected from the project.

(300)BUDGET ESTIMATES: SUMMARY

	Item	BUDGET			(in Rupees)
	N	1st Year	2nd Year	3rd Year	Total
A.	Recurring				
	1.Salaries/ wages	1,93,200	3,76,800	3,76,800	9,46,800
	2. Consumables	10,000	25,000	25,000	60,000
	3. Travel	15,000	30,000	30,000	75,000
	4. Other costs	70,200	2,24,000	1,44,000	4,38,200
B.	Equipment	--	3,80,000	--	3,80,000
	Grand total (A+B) Total FEC*	2,88,400	10,35,800	5,75,800	19,00,000

***FEC- Foreign Exchange Component**
Foreign Exchange component (in US$) equivalent of rupee amount at the prevailing rates may be furnished.
N.B. Entries here should match with those given in section 310 to 350; justification for each item is to be given in Section following it that is section 311, 321, 331, 341 and 351.

310. BUDGET FOR SALARIES/WAGES

		BUDGET			(in Rupees)
Designation & number of persons	Monthly Emoluments	1st Year (m.m.*)	2nd Year (m.m.)	3rd Year (m.m.)	Total (m.m.)
Research Associate	16,100	1,93,200 (12)	1,93,200 (12)	1,93,200 (12)	5,79,600 (36)
JRF	13,300	--	1,59,600 (12)	1,59,600 (12)	3,19,200 (24)
Attendant	4,000	--	24,000 (6)	24,000 (6)	48,000 (12)
Total		1,93,200	3,76,800	3,76,800	9,46,800

This is a sample proposal to DST, Govt. of India.
To be used as a guideline only.

***m.m.:man months to be given within brackets before the budget amount**

311. Justification for the manpower requirement

One person is required with M. Tech or equivalent degree to conduct the advanced analysis. The position requested is Research Associate with a pay of Rs. 11,500/- per month (as per DST O.M. No.SP/S9/2-23/97 dt. 24.2.98). Another person would be taken in the second year onwards in order to do the analysis of composite materials and carry out the experiments. This candidate is placed in the JRF category with pay of Rs.9,500/- per month. Since there is a provision to pay House Rent and Medical allowance, about 40% additional amount is put in the budget.

320. BUDGET FOR CONSUMABLE MATERIALS

		BUDGET			(in Rupees)
Item		**1st Year**	**2nd Year**	**3rd Year**	**Total**
	Q*				
	B**	10,000	25,000	25,000	60,000
	F***	--	--	--	--
Total	**B**	10,000	25,000	25,000	60,000
	F	--	--	--	--

***Q: Quantity or number, ** Budget, ***F: Foreign Exchange Component in US$**

321. Justification for costly consumable (if not provided for in Section 231 i.e. Methodology)

Since the experimental work will start from 2nd year, link materials, small parts, cables, electronic circuitry, etc. may be required besides regular requirement of papers, printer cartridges, floppies, CDs, etc., the budget in the last two years are kept little high.

330. BUDGET FOR TRAVEL

		BUDGET			(in Rupees)
		1st Year	**2nd Year**	**3rd Year**	**Total**

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To be used as a guideline only.

	Travel (Only inland travel)	15,000	30,000	30,000	75,000

331. Justification for intensive travel, if any.

A few trips are envisaged to discuss the problem with the people working in this area, visit places having similar set-ups, finalizing the purchases with the suppliers, and attending conferences/symposium for the dissemination of the result. In the second and third years, it is more because there may be more visits to attend seminars/conferences.

340. BUDGET FOR OTHER COSTS/CONTINGENCIES

		BUDGET			**(in Rupees)**
		1st Year	**2nd Year**	**3rd Year**	**Total**
	Other costs/ Contingency costs	6,000	12,000	12,000	30,000
	Consumable	4,200	12,000	12,000	28,200
	Institute Overheads (20%)	60,000	2,00000	1,20,000	3,80,000
	Total	70,200	2,24,000	1,44,000	4,38,200

341. Justification for specific costs under other costs, if any.

Contingencies are kept for fabrication charges, buying books (if necessary), etc.

350. BUDGET FOR EQUIPMENT

Sl. No.	**Generic name of the Equipment along with make & model**	**Imported/Indigenous**	**Estimated Costs (in Foreign Currency also)***	**Spare time for other users (in %)**
1	AC Servo Motors (2)	Imported#	1,30,000	20%
2	2-axes Controller	Imported	1,20,000	20%

	card			
3	Data Acquisition System	Imported	70,000	20%
4	PC based Controller Interface	Imported	60,000	20%
		Total	3,80,000	

<u>* includes transport, insurance and installation charges.</u>

<u># Available in Indian Rupees</u>

This is a sample proposal to DST, Govt. of India.
To be used as a guideline only.

351. Justification for the proposed equipment.

AC motors are proposed for feedback control of the systems. Controller cards are necessary to be connected with through a PC interface. The data acquisition system is necessary to get the encoder readings to compare with the simulation results.

410. Time Schedule of Activities through BAR Diagram

Activities	**Months**					
	1-6	**7-12**	**13-18**	**19-24**	**25-30**	**31-36**
Literature survey						
Staff Recruitment						
Computer upgradation						
Flexible analyses with 1 & 2 links						
Composite link design						
Experiment development						
Validation						
Debugging & report						

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To be used as a guideline only.

420. List of facilities being extended by parent institution(s) for the project implementation.

A) Infrastructural Facilities:

Sr. No.	Infrastructural Facility	Yes/No/ Not required Full or sharing basis
1.	Workshop Facility	Yes
2.	Water & Electricity	Yes
3.	Laboratory Space/ Furniture	Yes
4.	Power Generator	Yes
5.	AC Room or AC	Yes
6.	Telecommunication including e-mail & fax	Yes
7.	Transportation	Yes
8.	Administrative/ Secretarial support	Yes
9.	Information facilities like Internet/ Library	Yes
10.	Computational facilities	Yes
11.	Animal/ Glass House	Not required
12.	Any other special facility being provided	Not Applicable

B. Equipment available with the Institute/ Group/ Department/ Other Institutes for the project:

Equipment available with	Generic Name of Equipment	Model, Make & year of purchase	Remarks including accessories available and current usage of equipment
PI & his group	CRO	HP, 2002	20%
PI's Department	Function Generator	Tektronix	20%
Other Inst In the region	Not Required	Not Required	Not Applicable

This is a sample proposal to DST, Govt. of India.
To be used as a guideline only.

430. Detailed Bio-data of the Investigator

Name: Dr. Subir Kumar Saha

Address: Department of Mechanical Engineering, IIT Delhi, Hauz Khas, New Delhi 110 016, Tel: 659 1135; Fax: 685 7753; Email: saha@mech.iitd.ac.in

Date of Birth: September 02, 1961

Institution's Address: IIT Delhi, Hauz Khas, New Delhi 110 016

Academic Qualifications:

Degree	*Year*	*College/Institute/University*	*Discipline/Thesis*
Ph. D	Oct., 1991	McGill University, Canada	Dynamics of Robotic Systems
M. Tech	May, 1985	IIT Kharagpur, India	Machine Tool Engineering
B.E	May, 1983	RE College, Durgapur, India	Mechanical Engineering

Experience

Duration	*From*	*Organization*	*Position*	*Responsibility*
Teaching				
2 yrs +	Jan.'00	IIT Delhi	Associate Prof.	Teaching/Supervision/ Research/Consultancy
3.5 yrs	July'96	-- do --	Assistant Prof.	-- do --
10 mos	Aug.'95	IIT Madras	Visiting Faculty	-- do --
Industrial				
3 yrs 9 mos	Nov.'91	R&D Center, Toshiba Corp., Japan	Research Scientist	Space robot simulation
8 mos	May'84	IISCO (SAIL), Burnpur, India	Management Trainee	M/c shop supervision
Others				

2 mos	May'02	McGill Univ., Canada	Visiting Researcher	Multibody dynamics
9 mos	May'99	Univ. of Stuttgart, Germany	Humboldt Fellow	Parallel robot dynamics

Professional Achievements

- *Patent*: One submitted in Japan, Feb'94
- *Design Registration*: Four, India, Mar'02
- *Publications [48]*: Journal 16 (Int. 13); Conf. Proc. 32 (Int. 20)
- *Software Developed*: **IIT Delhi**—RIDIM'99 (Robot Control); RFDSIM'99 (Robot simulation); VRL'98 (Virtual Robotics Laboratory). **Toshiba Corp**.—SpaceDyn'95 (Space robot dynamics). **McGill University**—OMNI'91 (AGV simulation)
- *Research and Consultancy*: Completed 5 (INR 1,722,000=US$34,440); On-going 5 (INR 11,362,00=US$22,724)

Honours

- *Humboldt Fellow*: Alexander von Humboldt Foundation, Germany, 1999.
- *Dean's Honors List*: McGill University, Canada, 1991 (for an excellent Ph. D. thesis)
- *Newspaper Interviews*: Nikkey Sangyo Shinbun [Japanese], Japan, 1993 (Sub: NOC method); The Nikkei Weekly [English], Japan, 1992 (Sub: Indian Engineer)
- *Who's Who*: Listed in MARQUIS Who's Who in the World, USA, 13th Ed., 1995; International Directory of Distinguished Leadership, ABI Inc., USA, 1999;
- *Journal Reviewers*: International Journal of Robotic Systems, USA; ASME Transactions: Journal of Mechanical Design; International Journal of the Robotics Society of Japan; IEEE Transactions on Robotics and Automation.

Professional Membership

- *Member*: IEEE (since 1991); SAE (since 1997); IE (since 1997) & AMM (since 1995), India

Extra-Curricular Activities

- *Foreign Languages*: Japanese (Fluent); French and German (Little)
- *Hobbies*: Traveling, Playing squash/badminton/tennis, Reading novels, Acting

Publications list (51):

Journal (16) [• Int. 13; o Nat. 3]

2001 (2)

This is a sample proposal to DST, Govt. of India.
To be used as a guideline only.

- SAHA, S.K., ``Dynamic simulation of serial manipulators using the UDU^T decomposition of the inertia matrix,'' Multibody System Dynamics, accepted in June 2001.
- SAHA, S.K., and Schiehlen, W.O., ``Recursive kinematics and dynamics for closed loop multibody systems,'' Int. J. of Mechanics of Structures and Machines, V. 29, N. 2, Aug., pp. 143-175.

1999 (2)

- SAHA, S.K., ``Dynamic modelling of serial multi-body systems using the decoupled natural orthogonal complement matrices,'' ASME J. of Applied Mechanics, V. 66, Dec. pp. 986--996.
- SAHA, S.K., ``Analytical Expression for the inverted inertia matrix of serial robots,'' Int. J. of Rob. Res., V. 18, N. 1, Jan., pp.116--124.

1997 (1)

- SAHA, S.K., ``A decomposition of the manipulator inertia matrix,'' IEEE Trans. on Rob. & Aut., V. 13, N. 2, Apr., pp. 301--304.

1996 (2)

- SAHA, S.K., ``Inverse dynamics algorithm for space robots,'' Trans. of the ASME, J. of Dynamic Systems, Measurement and Control, V. 118, Sept., pp. 625--629.
- SAHA, S.K., ``A unified approach to space robot kinematics,'' IEEE Trans. on Rob. & Aut., V. 12, N. 3, June, pp. 401--405.

1995 (4)

- SAHA, S.K., ``A concept of Primary Body for kinematics of free-flying space robots,'' Systems, Control and Information Trans., Japan, V. 8, N. 10, pp. 529--534.
- SAHA, S.K., Angeles, J., Darcovich, J., ``The design of kinematically isotropic rolling robots with omnidirectional wheels,'' Int. J. of Mechanism and Machine Th., V. 30, N. 8, pp. 1127--1137.
- SAHA, S.K., ``Plant robotics in India,'' J. of Plant Engineering, Silver Jubilee Issue, Oct., pp. 59--62.
- SAHA, S.K., Chakrabarti, A.K., and Chattopadhyay, A.B., ``A comparative study on the performance of cast ZA alloy bearings,'' Trans. Indian Institute of Metals., V. 48, N. 2, pp. 121-123.

1991 (2)

- Angeles, J., SAHA, S.K., and Lopez-Cajun, C.S., ``The design of cam mechanisms with translating flat-face followers under curvature constraints,'' ASME J. of Mechanical Design, V. 116, Mar., pp. 306--310.
- Angeles, J., SAHA, S.K., Gonzalez-Palacios, M., and Lopez-Cajun, C.S., ``The design optimization of cam mechanisms with oscillating flat-face followers under curvature constraints,'' ASME J. of Mechanical Design, V. 116, Mar., pp.311--314.

1991 (2)

**This is a sample proposal to DST, Govt. of India.
To be used as a guideline only.**

- SAHA, S.K., and Angeles, J., ``The mathematics of motion simulation: a case study," Int. J. of Mathematical & Computer Modelling, V. 15, N. 10, pp. 61--77.
- SAHA, S.K., and Angeles, J., ``Dynamics of nonholonomic mechanical systems using a natural orthogonal complement," ASME J. of Applied Mechanics, V. 58, Mar., pp. 238--243.

1987 (1)

- o Saha, D.K., Mohanty, O.N., SAHA, S.K., and Chattopadhyay, A.B., ``Cryo-jet cooled grinding," J. of the Association of Engineers, India, V. 62, pp. 36—42.

Conference Proceedings (32) [• Int. 20; o Nat. 15]

2002 (5)

- SAHA, S.K., ``Modeling constrained systems with the natural orthogonal complement: Recursive algorithms,'' Notes of the Workshop T3/Tutorial T2: Topics in Modeling, Simulation and Implementation of Real-Time Robotic Systems, *IEEE Conf. on Robotics and Automation*, May 11-15, Washington DC, pp. IV1-29.
- SAHA, S.K., ``Mechatronics-What and why?,'' (Abstract) Lecture Notes, ISTE Short Term Training Programme on Mechatroincs & Automation, SLIET, Longwal, Jan. 7-18, pp. SKS-I-1-2.
- SAHA, S.K., ``Modelling and simulation of physical systems,'' (Abstract) Lecture Notes, ISTE Short Term Training Programme on Mechatronic & Automation, SLIET, Longwal, Jan. 7-18, pp. SKS-II-1.
- SAHA, S.K., ``Robotics,'' (Abstract) Lecture Notes, ISTE Short Term Training Programe on Mechatronics & Automation, SLIET, Longwal, Jan. 7-18, pp. SKS-III-1
- SAHA, S.K., Kar, I.N., Kumar, A., Jha, R., Momaya, K., Bhalla, M., and Gupta H., K., ``A straightening strategy for the automobile industries," Proc. of the 2nd Int. SAE-INDIA Mobility Conference, IIT Cheannai, Jan. 10-12, pp. 393-398

2001 (4)

- Saha, S.K., ``An inverse dynamics software for serial robots," Proc. of the Nat. Conf. of Mach. and Mech. (NACOMM), IIT Kharagpur, Dec. 21-22, pp. 131-138.
- o Bhangale, P., Saha, S.K., and Agrawal, V.P., ``Concept of decoupled natural orthogonal complement (DeNOC) for robot architecture selection," Proc. of the Nat. Conf. of Mach. (NACOMM), IIT Kharagpur, Dec. 21-22, pp. 177-184.
- o Chandrashekhar, SAHA, S.K., and Kundra, T.K., ``Modelling of a CNC milling positioning system," Proc. of the IE(I) XVth Nat. Convention of Production Engineers & Nat. Sem. on Emerging Convergence in Manufacturing Systems, Bhopal, Mar. 3-4, pp. 49FA-54FA.
- o Dorlikar, P., Bhangale, P., SAHA, S.K., and Agrawal, V.P., ``Study of robots using ADAMS, Proc. of the IE(I) XVth Nat. Convention of Production Engineers

**This is a sample proposal to DST, Govt. of India.
To be used as a guideline only.**

& Nat. Sem. on Emerging Convergence in Manufacturing Systems, Bhopal, Mar. 3-4.

2000 (2)

- SAHA, S.K., ``Dynamics for machine tool component design," Proc. of the 19th All India Manufacturing, Design and Research (AIMTDR) Conf., IIT Madras, Chennai, Dec. 14-16, pp. 261--266.
- Jain, A., SAHA, S.K., and Mukherjee, S., ``Design methodology for a HEXAPOD machine tool," Proc. of the 19th AIMTDR, IIT Madras, Chennai, Dec. 14-16, pp. 279--284.

1999 (3)

- SAHA, S.K., ``Simulation of industrial manipulators based on the $\mathbf{UDU}^T$ decomposition of inertia matrix," Proc. of the EUROMECH Colloquium, Lisbon, Portugal, Sept. 20-23.
- Mathan, R., SAHA, S.K., Singh, S.P., ``Behaviour of robot links made of fiber reinforced composite material," Proc. of the Int. Symp. in Motion & Vibration Control in Mechatronics, Tokyo, Japan, Apr. 6-7.
- Baghla, D., Anurag, A., SAHA, S.K., Sharma, Prasenjit, S., and Mehta, G.R., ``Development of a hanging planar robotic arm (HaPRA)," Proc. of the 11th ISME Conf., IIT Delhi, Feb. 3-5, pp. 93-98.

1998 (3)

- SAHA, S.K., and Petkar, S., ``Dynamic modelling for serial manipulator control," Proc. of the Int. Symp. on Intelligent Robotics Systems, Bangalore, India, Jan. 10-12, pp. 351-358.
- Arora, D., SAHA, S.K., and Basamboo, A., ``A simple gripper design for cylindrical objects," Proc. of the 18th AIMTDR Conf., Dec., 21-23, IIT Kharagpur, pp. 496-5501.
- SAHA, S.K., "Virtual Prototyping of Mechanical Systems," Proc. of the SERC School, IIT Delhi, Nov. 2-14, pp. 162-169.

1997 (4)

- Momaya, K., and SAHA, S.K., ``Technological upgradation in Japanese Firms: A case of large high-tech firms," Proc. of the Int. Conf. on Management of Technology, IIT, Delhi, India, Dec. 21-24, pp. 325--333.
- SAHA, S.K., and Goel, S.K., ``Dynamic modelling of serial-link mechanisms," Proc. of the Nat. Conf. on Machines and Mechanisms, IIT Kanpur, India, Dec. 12-13, D-49--D-54.
- SAHA, S.K., ``Robotics in India,"Proc. of the Inst. of Engrs. (I) Nat. Sem. on Modern Trends in Manufacturing Technology, Nov. 6-8, New Delhi, pp. 215--221.
- Venugopal, S, and SAHA, S.K., ``Interactive design for industrial robots," Proc. of the AIMTDR Conf., Jan 9-11, Warangal, pp. 201--205.

1996 (1)

- SAHA, S.K., ``Symbolic generation of the inertia matrix," Abstracts of the Int. Congress on Theoretical & Applied Mechanics, Kyoto, Japan, Aug. 25-31, 1996.

1995 (3)

- SAHA, S.K., ``Dynamic Modeling using the DeNOC," Proc. of the Int. Conf. on Automation, Indore, India, Dec. 12-14.
- SAHA, S.K., ``Symbolic factorization of inertia matrix for space robot simulation," Proc. of the 34th SICE Annual Conf., Sapporo, Japan, July 26-28, Int. Sess., pp. 1137--1142.
- SAHA, S.K., ``The $\mathbf{UDU}^T$ decomposition of manipulator inertia matrix," Proc. of the IEEE Int. Conf. on Robotics and Automation, Nagoya, Japan, May 21-27, V. 3, pp. 2829--2834.

1994 (2)

- SAHA, S.K., ``An efficient algorithm for kinematic control of free-floating space robots," Proc. of the Asian Control Conf., Tokyo, Japan, July 27-30, V. 1, pp. 281--284.
- SAHA, S.K., ``A new method for kinematics of space robots," Proc. of the Japan-USA Symp. on Flexible Aut., Kobe, Japan, July 11-13, V. II, pp. 447--450.

1993 (2)

- SAHA, S.K., ``Modeling and simulation of space robots," Proc. of the IEEE/RSJ Int. Conf. on Intelligent Robots & Systems, Yokohama, Japan, July 26--30, V. 3, pp. 2033--2040.
- SAHA, S.K., Angeles, J., and Darcovich, J., ``The kinematic design of a 3-dof isotropic mobile robot," Proc. of the IEEE Int. Conf. on Robotics and Automation, Atlanta, USA, May 2-7, V. 1, pp. 283--288.

1991 (2)

- SAHA, S.K., and Angeles, J., ``The formulation of kinematic constraints in design-oriented machine dynamics," Proc. of the ASME Des. Aut. Conf., Miami, USA, Sept. 22-25, pp. 115--122.
- SAHA, S.K., and Angeles, J., ``On the formulation of linear homogeneous velocity constraints in mechanical systems," Proc. of the 13th Canadian Cong. of Appl. Mech., University of Manitoba, Winnipeg, Canada, June 2-6, V. 2, pp. 658--659.

1989 (3)

- Angeles, J., Lopez-Cajun, C.S. and SAHA, S.K., ``Curvature constraints in the design of cam mechanisms. Part I. Translating flat face followers," Proc. of the ASME Des. Aut. Conf., Montreal, Canada, V. 2, pp. 259--264.
- Angeles, J., Lopez-Cajun, C.S and SAHA, S.K., ``Curvature constraints in the design optimization of cam mechanisms. Part II. Oscillation flat face followers," Proc. of the ASME Des. Aut. Conf., Montreal, Canada, V. 2, pp. 265--269.
- SAHA, S.K., and Angeles, J., ``Kinematics and dynamics of a three-wheeled 2-dof AGV," Proc. of the IEEE Conf. on Robotics and Automation, Scottsdale, USA, May 14-19, V. 3, pp. 1572--1577.

This is a sample proposal to DST, Govt. of India.
To be used as a guideline only.

1986 (1)

- SAHA, S.K., Chakraborty, A.K., and Chattopadhyay, A.B., ``On machinability characteristics of zinc-aluminium alloys," Proc. of the Int. Symp. on Zinc-Aluminum Alloys: 25th Annual Conf. of Metallurgists, Toronto, Canada, Aug. 17-20, pp. 59--70.

Patent list, if any:

- *Patent*: One submitted in Japan, Feb'94
- *Design Registration*: Four, India, Mar'02 (Carpet Hand Tools)

List of Projects implemented:

1. Robot Design Using Dynamic Motion Study, DST (Scheme for Young Scientists), 1997-1999.
2. Investigation and Optimum Selection of Mechatronic Components, MHRD (Thrust Area Project), 1999-2001.
3. Data Base and Software Development for an Automatic Rack-bar Straightening Machine, Sona Koyo Steering Systems (P) Ltd., 2000-2001.

430. Detailed Bio-data of the Co-Investigator

Name: Dr. S.P. Singh

Address: Department of Mechanical Engineering, IIT Delhi, Hauz Khas, New Delhi 110 016, Tel: 659 1135; Fax: 685 7753; Email: singhsp@mech.iitd.ac.in

Date of Birth: 20 Jan 1968

Institution's Address: IIT Delhi, Hauz Khas, New Delhi 110 016

Academic Qualifications:

**This is a sample proposal to DST, Govt. of India.
To be used as a guideline only.**

Degree	Institution	Year	Marks	Honors
Ph.D. (Mech.Design)	IIT, Delhi	1992	10.0/10	Highest CGPA
M.Tech (Design of Mechanical Equipment)	IIT, Delhi	1989	10.0/10	Highest CGPA.
B.E. Hons.(Mechanical)	Punjab Univ.	1987	89%	First in University.
Pre- Engineering	Punjab Univ.	1983	84%	First in Punjab State

Experience

Period	Post	Department	Institute
July 96 onwards	Asstt. Prof.	Dept. of Mechanical Engg.	IIT, Delhi
Jan 95 to July 96	Asstt. Prof.	Mech. M/c Design &Automation Engg	Regional Engineering College, Jalandhar.
Sept 93 to Jan 95	Lecturer	Dept. of Mech. And Industrial Engg.	Thapar Institute of Engg. and Technology Patiala.
Jan 89 to Aug 89	Lecturer	Mechanical Engg. Dept.	G.N. Engineering College, Ludhiana.

Publications list (Title of paper, authors, Journal details, pages, year etc.)

JOURNAL

1. S.P. Singh and K. Gupta, “Damped free vibrations of Layered Composite Cylindrical Shells”, Journal of Sound and Vibration, Vol. 172, No.2 (1994) pp191-209.
2. S.P.Singh and K. Gupta, “Composite Shaft Rotordynamic Analysis using a Layerwise Shell theory” Journal of Sound and Vibration Vol. 191 No. 5 (1996) pp. 739-756.
3. S.P.Singh and K. Gupta, “Free Damped Flexural Vibration Analysis of Composite Cylindrical Tubes using Beam and Shell theories". Journal of Sound and Vibration Vol. 172, No.2 (1994) pp. 171-190.
4. S.P.Singh and K. Gupta, “Rotordynamic Experiments on Composite Shafts,” ASTM Journal of Composite Technology and Research” Vol. 18, No. 4 (1996) pp. 256-264.
5. S.P.Singh and K. Gupta and H.B.H. Gubran, “Developments on Composite Material Shafts” International Journal of Rotating Machinery 1997 Vol. 3, pp. 189-198.
6. S.P.Singh and K. Gupta, “Dynamic Analysis of Composite Rotors” International Journal of Rotating Machinery, Vol2, No. 3(1996) pp. 179-186.
7. K.Gupta and S.P.Singh , “Damping Measurements in Fibre Reinforced Composite Shafts” Journal of Sound and Vibration , Vol. 211 No. 3 (1998) pp. 513-520.

**This is a sample proposal to DST, Govt. of India.
To be used as a guideline only.**

8. Rakesh Chandra, S.P.Singh and K. Gupta, "Damping Studies in fiber reinforced Composites – a review" Composite Structures, Vol.46 (1999) pp. 41-51.
9. H.B.H. Gubran , S.P.Singh and K. Gupta, "Stresses in Composite Shafts subjected to Unbalance excitation and Transmitted Torque, International Journal of Rotating Machinery, 2000.
10. Rakesh Chandra, S.P. Singh and K. Gupta, " Role of interface on Damping Predictions for Three Phase Composites" To appear in Defence Science Journal.
11. Rakesh Chandra, S.P. Singh and K. Gupta, " Micromechanical Damping Models for fiber reinforced composites : A comparative Study" Composites Part A Vol 33 No.6 , pp. 787-796, June 2002..

CONFERENCE

12. S.P.Singh and K. Gupta, "Modal Testing of Tubular Composite Shafts" Proceedings of International Modal Analysis Conference, Florida (USA) , 1993 , pp.733-739.
13. S.P.Singh and K. Gupta, "Dynamic Analysis of Composite Rotors", Proceedings of 5th International Symposium on Rotating Machinery (ISROMAC-5) Hawai (1994).
14. H.B.H. Gubran , S.P.Singh and K. Gupta, "Stresses in Composite Shafts subjected to Unbalance excitation and Transmitted Torque", Proceedings of 7th International Symposium on Rotating Machinery (ISROMAC-7) 22-26 Feb, 1998, Honolulu, USA pp. 96-105.
15. Harpreet Singh and S.P.Singh, " Active Vibration Control of a Beam Using Virtual Instrumentation Software" International Conference on Smart Materials , Structures And Systems , 7-10 July,1999, Indian Institute of Science, Banglore.
16. S.P. Singh, "Development of Fibre Reinforced Composite Shafts", Proceedings of 5th Japan India Seminar on Manufacturing Science of Advanced Composite Materials, Institute of Industrial Science, University of Tokyo, October 19-24, 1998.
17. R. Mathan, S.K.Saha and S.P.Singh, "Behaviour of Robot Links made of Fiber Reinforced Composite Materials", Pioneering International Symposium on MOVIC in Mechatronics, Tokyo, April 6-7, 1999.
18. S.P.Singh and K. Gupta, "Experimental Studies on Composite Shafts" Presented at International Conference on Advances in Mechanical Engineering, Dec 20-22, 1995, IISc, Bangalore, pp. 1205-1220.
19. S.P.Singh and K. Gupta, "Dynamics of Composite Rotors", INDO-US Symposium on Emerging Trends in Vibrations and Noise Engineering, 18-20 March 1996, IIT, Delhi.
20. Kadre, K. Gupta and S.P.Singh "Design Alternatives for Composite Material Driveshafts, Proceedings of National Symposium on Developments in Advanced Composites and Structures, DRDL, Hyderabad, 1994, pp. 17-24.
21. S.P.Singh and A.K. Kishore "Damping Based Design with Composite Materials" , IUTAM-IITD International Winter School on Optimum Dynamic Design using Modal Testing and Structural Dynamic Modification, 15-19 Dec, 1997 pp. 445-453.

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22. Harpreet Singh , S.P.Singh and V.P. Agrawal " Active Vibration Control using Virtual Instrumentation Software" , Proceedings of the 11th ISME Conference on Mechanical Engineering on Trends in Mechanical Engineering Education & Research , 3 – 5 Feb, 1999 pp. 112-117.
23. Rakesh Chandra , S.P.Singh and K.Gupta " Comparative Study of Damping Models for Fibre Reinforced Composites", Proceedings of the 11th ISME Conference on Mechanical Engineering on Trends in Mechanical Engineering Education & Research , 3 – 5 Feb, 1999 pp. 489-494.
24. Umesh M . Kalokhe, S.P.Singh and Atul Bhaskar " Identification of damping from transient response " Presented at 11th ISME Conference on Mechanical Engineering on Trends in Mechanical Engineering Education & Research , 3 – 5 Feb, 1999 .
25. Rakesh Chandra , S.P.Singh and K.Gupta "FEM Model for evaluation of fiber – reinforced composites" National Symposium on Dynamics , FEA in Industry-Recent Trends, IIT, Madras, Aug 7, 1998 pp. 109-114.
26. Harpreet Singh, S.P. Singh and V.P. Agarwal, "Efficient Modal Control of Vibrations" presented at INDO-US symposium on Recent Trends in Vibrations and Noise (INDUSVAN), Ohio State University Dec 8-14, 2001.
27. K. Kannan, S. P. Singh and K. K. Pujara, "Noise control in a rectangular duct using Active Structural Panel" to be presented in International Symposium of Smart Materials and Structures, Proceedings of ISSS-SPIE-2002, IISc Bangalore, July 17-19, 2002.
28. Manu Sharma, S. P. Singh and B. L. Sachdeva. Fuzzy logic based active vibration control of beams using piezoelectric patches. to be presented in International Symposium of Smart Materials and Structures, Proceedings of ISSS-SPIE-2002, IISc Bangalore, July 17-19, 2002.

List of Projects implemented

Sponsoring Agency	Project Name	Status	Investigators	Amount (Lakhs)
IRD	Fabrication and Analysis of Composite Structural Elements	Completed	S.P. Singh*	0.50
ARDB	Dynamics of High Speed Rotating Composite Shafts	Completed	K.Gupta*, S.P.Singh	15.00
ISRO	Rotordynamic Performance Analysis of Cryogenic Engine Turbopump-Unbalance Response, Stability and Transient Response	Pending	K.Gupta*, B.C. Nakra, Om Prakash, S.P. Singh	5.00
NRB	Design and Development of Composite Ship Propulsion Shaft	Ongoing	K.Gupta*, S.P.Singh	14.68
MHRD	Active Vibration Control of Structures using Piezoelectric Materials	Ongoing	S.P. Singh*, K.Gupta	6.00

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DST	Passive and Active Control of Vibration and Noise in Machine and Structures	Ongoing	K.Gupta*, B.C. Nakra, T.K. Kundra, S.P. Singh, N. Tondon	62.00
DST	Vibration Control by use of active constrained layer damping	Ongoing	S.P. Singh*	8.00
Consultancy Projects				
Client Agency	**Project Name**	**Status**	**Investigators**	**Amount (Lakhs)**
AFL Gurgaon	Analysis Vibration Severity and its effects thereoff at AFL Gurgaon	Completed	S.P. Singh*, A.K. Nagpal	1.50
Carrier Aircon Ltd.	Noise reduction in 1 Ton Window Room Air Conditioner	Pending	S.P. Singh, N.Bhatnagar*	1.00
Premium Moldings and Castings	Measurement of Natural Frequencies and Polar Inertia of Steering Wheel	Completed	S.P. Singh*, K. Gupta	0.09
Boremann India, Ltd.	Calibration of a Vibration Meter and Sound Level Meter	Completed	S.P. Singh*, K. Gupta	0.07
Sherman International (P) Ltd.	Vibration Analysis and Calibration osf Siesmoprobes	Completed	K.Gupta*, S.P.Singh	0.12
Sherman International (P) Ltd.	Vibration Analysis and Calibration osf Siesmoprobes	Completed	S.P. Singh*,K.Gupta	0.06
Sherman International (P) Ltd.	Vibration analysis and Calibration of Snapshot Pens Instrument and Siesmoprobes	Completed	S.P. Singh*, K. Gupta	0.12
Burma Electro Corporation	Resonance Frequency Test on Dampers for Zebra ACSR	Completed	S.P. Singh*, K. Gupta	0.09
M/s Devent forms Pvt. Ltd.	Calibration of sound level meter	Completed	S.P. Singh*, N. Tondon	0.03

450. Details of Research Projects being implemented/ completed/ submitted by the Investigator

For Dr. S.K. Saha

This is a sample proposal to DST, Govt. of India.
To be used as a guideline only.

1. Project Title: Robot Design Using Dynamic Motion Study
Project Status: Completed

Completed-duration, period, funding agency and total cost:
1997-1999, DST (Scheme for Young Scientists), 2.05 lakhs

Summary of the project:

In this project, recursive dynamics algorithms are developed. Two C++ programs are written for the inverse (for Control)/forward (for Simulation) dynamics of serial-chain robots (Saha, 1999a).

Major Results/ Highlights of the project including achievement (publications, patents etc.):

- Two journal and two conference papers could be published;
- The C++ programs are used in the Robotics/Multibod Dynamics courses at IIT Delhi
- The above programs are made available free of cost for any academic institutions (www.angelfire.com/sc/saha)

2. Project Title: Investigation and Optimum Selection of Mechatronic Components (Co-Pis: Prof. T.K. Kundra, Dr. S. Mukherjee)

Project Status: Completed

Completed-duration, period, funding agency and total cost:
1999-2001, MHRD (Thrust Area Project), 8.0 lakhs

Summary of the project:

In this project, two major facilities, namely, an AC servo controlled XY table and an intelligent conveyor system, are developed. The simulation studies of the above two systems and their experimental verifications were carried out.

Major Results/ Highlights of the project including achievement (publications, patents etc.):

- Two M. Tech theses
- One conference paper

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3. Project Title: Data Base and Software Development for an Automatic Rack-bar Straightening Machine (Co-PI: Dr. I.N. Kar, Dr. K. Momaya)

Project Status: Completed

Completed-duration, period, funding agency and total cost:
2000-2001, Sona Koyo Steering Systems (P) Ltd., 2.12 lakhs

Summary of the project:

In this project, a controlling strategy for the rack-bar straightening operation is proposed based on the existing straightening process.

Major Results/ Highlights of the project including achievement (publications, patents etc.):

- A fuzzy logic based control algorithm is suggested to the companay;
- An international conference paper is published in 2001.

4. Project Title: Modeling and Simulation Tools for Shape Realizability of Machined Components (PI: Dr. PVM Rao)

Project Status: Ongoing

Completed-duration, period, funding agency and total cost:
Started March 1999 (expected to be completed in Dec. 2002), Dept. of Information Technology, 33.12 lakhs

Summary of the project:

In this project, an algorithm is developed from a set of measurements to identify the errors introduced to an used CNC machine tools.

Major Results/ Highlights of the project including achievement (publications, patents etc.):

- An artifact is designed to capture the kinematics errors of a CNC machine tool
- CaliNC software for the error identification and CNC program modification to improve the accuracy of the job

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5. Project Title: Technological Improvement of Tools and Processes used by craftsman in Indian Carpet Industry (PI: Prof. R. Prasad)

Project Status: Ongoing

Completed-duration, period, funding agency and total cost:
Started March 2000 (expected to be completed in Oct. 2002), Development Commissioner (Handicrafts), 10.12 lakhs

Summary of the project:

In this project, several tools, e.g., carpet loom, washing machines, etc. were developed for the carpet industries.

Major Results/ Highlights of the project including achievement (publications, patents etc.):

- New designs for a) Carpet Loom; b) Washing Machine; c) Squeezing machine

The above machines are now under field trials at Bhadohi, Jaipur and Agra.

450. Details of Research Projects being implemented/ completed/ submitted by the Investigator(s)/Co-Investigators including Investigator(s) Name & Institute
Project Title
Project Status:

Completed-duration, period (from.... to.....), funding agency and total cost
On-going-duration, date of start, funding agency and total cost proposed-duration, funding agency where submitted and total cost

Summary of the project
Major Results/ Highlights of the project including achievement (publications, patents etc.), for *<u>completed projects</u>*
Up-to date Technical progress report for *<u>on-going projects.</u>*

For Dr. S.P. Singh, Please see the projects implements in 430

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500. Any other relevant matter. *NIL*

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File No**________________

1. Title: *Study and Analyses of Light Weight, High Speed Robot Arms*

2. Proposed Budget for 3 years:

2.1 Total: 19.0 lakhs

2.2 Equipment: 3.8 lakhs
(Please give list of major/ minor equipment)

AC Servo Motors (2)
2-axes Controller card
Data Acquisition System
PC based Controller Interface

2.3 Staff (proposed research staff): 9,46,800 (RA, JRF, Attendent)

2.4 Other Recurring costs:
Consumable: 60,000
Travel: 75,000
Contingency: 30,000
Any other expenses: 4,08,200

3. Date of receipt :**

4. PI Name, Designation & Address:

Dr. S.K. Saha, Associate Professor, Mech. Eng. Dept., IIT Delhi, Hauz Khas, New Delhi 110 016

5. Date of Birth: Sept. 02, 1961

6. Co-Investigator(s) details:

Dr. S.P. Singh, Associate Professor, Mech. Eng. Dept., IIT Delhi, Hauz Khas, New Delhi 110 016

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7. Date of Birth(s): Jan 20, 1968

8. Other projects with the PI/Co-PI(s) :

Sr. No.	Title	Cost (in rupees)	Duration	Agency
For Dr. S.K. Saha				
1	Robot Design Using Dynamic Motion Study (Completed)	2.05 lakhs	2 years	DST (SYS)
2	Investigation and Optimum Selection of Mechatronic Components (Completed)	8.0 lakhs	2 years	MHRD (Thrust Area)
3	Data Base and Software Development for an Automatic Rack-bar Straightening Machine (Completed)	2.12 lakhs	7months	Sona Koyo Steering Systems
4	Modeling and Simulation Tools for Shape Realizability of Machined Components	33.12 lakhs	3 years	DIT
5	Technological Improvement of Tools and Processes used by craftsman in Indian Carpet Industry (On-going)	10.12 lakhs	18 months	DC (Handicrafts)
For Dr. S.P. Singh (Only On-going sponsored projects)				
1	Design and Development of Composite Ship Propulsion Shaft	14.68 lakhs	2 years	NRB
2	Active Vibration Control of Structures using Piezoelectric Materials	6.0 lakhs	3 years	MHRD
3	Passive and Active Control of Vibration and Noise in Machine and Structures	62.0 lakhs	3 years	DST
4	Vibration Control by use of active constrained layer damping	8.0 lakhs	2 years	DST

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Annexure

**List of Programme Advisory Committees (existing)
(Please enter one of these at Section 104: Sub Area)**

Chemical Sciences (3 PACs)

i) Inorganic Chemistry
ii)Organic Chemistry
iii) Physical Chemistry

Earth & Atmospheric Sciences (2 PACs)

i) Atmospheric Science
ii)Earth Science

Engineering Sciences (5 PACs)

i) Chemical Engineering
ii)Electrical, Electronics and Computer Engineering
iii)Materials, Mining and Mineral Engineering
iv)Mechanical Engineering and Civil Engineering
v)Robotics and Manufacturing

Life Sciences (4 PACs)

i) Animal Sciences
ii)Biophysics, Biochemistry and Molecular Biology
iii) Health Sciences
iv) Plant Sciences

Mathematical Science (1 PAC)

Physical Sciences (3 PACs)

i) Condensed Matter Physics and Materials Science
ii)Lasers, Optics, Atomic and Molecular Physics
iii) Plasma, High Energy, Nuclear Physics,

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Astronomy & Astrophysics and Nonlinear dynamics