MANAV RACHNA
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MANAV RACHNA UNIVERSITY
Declared as State Private University vide Haryana Act 26 of 2014

PROGRESS REPORT 2022-23

Manav Rachna University

Declared as State Private University vide Haryana Act 26 of 2014

SUSTAINABLE DEVELOPMENT GOALS

Content

1. Preamble

Industry, Innovation, and Infrastructure," aims to build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation. This goal focuses on enhancing technological capabilities, improving access to quality infrastructure, and driving economic growth through innovation, while ensuring environmental sustainability. It is crucial for achieving long-term economic development and addressing global challenges such as climate change and inequality.

Manav Rachna University contributes significantly to SDG 9 by driving innovation and research in sustainable technologies and infrastructure. Through cutting-edge research in areas like renewable energy, green manufacturing, and smart cities, they develop solutions that promote sustainable industrialization. Universities also equip students with the skills needed for the green economy and foster entrepreneurship through innovation hubs and partnerships with industry. By collaborating with governments and industries, they help shape policies and practices that support resilient, inclusive, and sustainable infrastructure development.

2. Research Publications

1. The Role of Emotional Intelligence in Effective Leadership

Summary: This research paper explores the growing importance of Emotional Intelligence (EI) in effective leadership, analyzing how EI impacts leadership effectiveness and organizational success. It examines the core components of EI—self-awareness, self-regulation, motivation, empathy, and social skills—and how these traits contribute to a leader's ability to manage emotions, engage employees, and foster positive team dynamics. The paper highlights the role of EI in conflict resolution, team cohesion, and creating a supportive organizational culture. Leaders with high EI are shown to improve relationships, performance, and overall organizational outcomes. While acknowledging challenges in measuring and developing EI, the review underscores its critical role in leadership, offering insights for both research and practice in enhancing leadership capabilities and workplace environments.

2. The Role of Emotional Intelligence in Effective Leadership

Summary: This research paper examines the integration of emotional intelligence (EI) training in teacher education programs, focusing on its impact on teaching effectiveness and student learning outcomes. The study reveals that teachers who undergo EI training show improved classroom management, communication skills, and

student engagement, with self-awareness and empathy playing key roles. The paper advocates for including EI training in teacher education to enhance teacher effectiveness and create a positive learning environment. It also highlights the broader social benefits of EI in promoting empathy, tolerance, and emotional well-being in education. This research contributes new insights to the field, emphasizing the value of EI in improving teaching quality and the overall educational experience.

3. Probing the Electro-Chemical and Thermal Properties of Polyaniline/MWCNT Nanocomposites

Summary: The tremendous interest for robust, clean energy storage devices to comprehend the growing needs of modern gadgets has led to exploration of materials having unprecedented electrochemical and interfacial properties. Here, the present study deals with the synergistic effects of multi walled carbon nanotubes and polyaniline nanocomposites on the electro-chemical and thermal properties for wide-range of applications. The microstructural, structural, and optical characterizations have been evaluated through scanning electron microscopy (SEM), transmission electron microscopy (TEM), X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), and UV-Vis spectrophotometry. The thermal stability of the product was also studied through thermal gravimetric analysis (TGA) and the room temperature electrical conductivity was also measured. An exceptional enhancement in thermal stability and conductivity has been observed apparently due to interfacial properties of polyaniline (PANI) and multiwalled carbon nanotubes (MWCNTs). Further,

in present study we are going to report a comparative analysis of thermal and electrical properties of PANI/MWCNT nanocomposites with different loadings of MWCNTs. The room temperature conductivity as calculated for 1%, 2%, 4% and 8% MWCNT loading is around 2.019, 3.075, 4.48, 8.73 S/cm respectively. The mechanism for thermal and electrical enhancements in PANI-coated MWCNT nanocomposites is also expounded.

Paul SJ, Singh SK, Tuteja J, Sand A, Chandra P. Probing the Electro-Chemical and Thermal Properties of Polyaniline/MWCNT Nanocomposites. JOTCSA. 2023;10(2):493-504.

4. Attosecond-XUV pulse generation using laser-based high-harmonic generation in argon gas

Summary: High harmonic cut-off in high harmonic generation (HHG) based photon source is limited which restricts its further applications. In this work, we study single laser and three optical lasers based HHG in argon gas and analyze the harmonic cut-off of HHG spectra and the generated photon pulse structure. It is observed that the high harmonic spectrum strongly depends on the laser parameters such as wavelength, pulse duration, laser intensities. An extreme-ultraviolet (XUV) photon pulse of 90 keV photon energy with 270 as FWHM photon pulse duration is demonstrated in single laser-based HHG. However, in three colour laser case, it is extended up to 273 eV with 131 as FWHM photon pulse duration. Effect of time delays in-between the lasers is also studied on HHG spectrum and on the generated photon pulse characteristics. Effect of carrier-envelope phase (CEP) of laser is also discussed on photon pulse characteristics.

Generation of such XUV-attosecond photon pulse is extremely important for the study of ultrafast dynamics in atoms and molecules.

5. **Self-focusing of a Bessel–Gaussian laser beam in plasma under density transition Summary:** The model given by Patil *et al.*, for the self-focusing of lowest-order Bessel– Gaussian laser beam, is revisited by introducing the exponential plasma density ramp in this paper. Plasma density changes due to combined effect of the relativistic and ponderomotive nonlinearities, which arise due to the nonuniform spatial profile of the

laser beam leading to stronger self-focusing. Under paraxial ray approximation, the expression for the evolution of laser-beam width parameter is obtained and solved numerically in order to achieve self-focusing. We have observed that as Bessel beam propagates through the plasma, it does not diffract and spread out, which is in contrast to the usual behavior of light that spreads out after being focused down to the small spot. Laser spot size decreases considerably under the presence of exponential density ramp. This study will be useful for better understanding the self-focusing mechanism of lasers as it becomes effective for the optimized parameters under the proposed situation. Bessel laser beams play an important role in enhancing the energy gain in laser-driven accelerators. In addition, for all laser-driven plasma-based accelerators, it appears possible to guide a laser beam over large distances using a plasma density channel, thus enhancing the acceleration length and the energy gain.

6. **Enhanced laser wakefield acceleration by a circularly polarized laser pulse in**

obliquely magnetized under-dense plasma

Summary: Laser wakefield acceleration is one of the prominent methods to obtain high energy charge particles. This method can be used to accelerate lighter charged particles like electrons to relativistic energy level. Energy enhancement of electrons depends on the properties of laser pulse as well as plasma. In this study, we have used a circular polarized laser pulse propagating (along z- axis) through under-dense plasma. An external oblique transverse static magnetic field is applied an arbitrary angle (at angle θθ with Y-axis in x–y plane). Effect of laser pulse strength (a), strength of external magnetic field (B0), and its arbitrary angle (θθ) on generated longitudinal wakefield, wake potential, change in relativistic factor and energy enhancement are calculated theoretically and curves are drawn. Optimized oblique angle for maximum wakefield and potential is calculated for selected parameters. This study is useful for obtaining an energy efficient acceleration technique for electron.

7. **Quadrupole interaction induced optical rectification and second harmonic generation in CdSe quantum dots**

Summary: Our research focused on exploring the second-order nonlinear susceptibility linked with optical rectification, second harmonic generation, and sum frequency generation in CdSe/ZnSe and CdSe/ZnS quantum dots, which are singly charged with electrons. We investigated these processes through intersublevel quadrupole transitions present in the conduction band. To calculate the confined energy levels in these dots, we used the effective-mass approximation and solved the three-dimensional Schrodinger

equation. Our predictions indicate an enhanced nonlinear susceptibility that is approximately three orders of magnitude greater than the bulk CdSe susceptibility. We also observed that the second-order nonlinear processes are dependent on the size of the dot, the surrounding matrix, and the polarization state of the incident photon beam.

8. Optimization of Electron Bunch Characteristics in Bubble Wakefield: Role of Different Linear Upward Density Ramp Profiles

Summary: Laser wakefield acceleration (LWFA) technique is used for the generation of electron beam of high quality. In future, these beams may be used to develop compact X- ray sources. In the present work, using a linearly polarized Gaussian laser pulse for electron acceleration, we have explored different linear upward density ramp structures for achieving better characteristics of the injected electron bunch employing Fourier–Bessel particle-in-cell simulations (FBPIC) code. Laser parameters and plasma density ramp profile are optimized for maximizing energy gain (E), minimizing injected electron bunch charge (Q) , and normalizing the rms emittance within the wake bubble. The optimized values of emittances are observed as $\epsilon x=3.69\times10-5$mrad and $\epsilon y=0.83\times10-5$mrad in 2.23-mm-long plasma channel for ramp lengths of Zramp=100μm and Zramp=20μm , respectively. Simulation results show weaker particle trapping in bubble for increasing the values of density ramp length, revealing that the injected electron bunch charge is strongly related to the plasma density ramp length. A minimum charge of ~277.26 pC trapped in the bubble and a maximum energy gain of 0.21 GeV are obtained for the plasma channel of 2.23 mm length.

9. Quadrupole interaction induced optical rectification and second harmonic generation in CdSe quantum dots

Summary: Our research focused on exploring the second-order nonlinear susceptibility linked with optical rectification, second harmonic generation, and sum frequency generation in CdSe/ZnSe and CdSe/ZnS quantum dots, which are singly charged with electrons. We investigated these processes through intersublevel quadrupole transitions present in the conduction band. To calculate the confined energy levels in these dots, we used the effective-mass approximation and solved the three-dimensional Schrodinger equation. Our predictions indicate an enhanced nonlinear susceptibility that is approximately three orders of magnitude greater than the bulk CdSe susceptibility. We also observed that the second-order nonlinear processes are dependent on the size of the dot, the surrounding matrix, and the polarization state of the incident photon beam.

10. Enhancement of electron-bunch quality in bubble domain utilizing plasma ramp profile with various density-hill widths in laser wakefield acceleration

Summary: The laser wakefield acceleration (LWFA) scheme is now a superb and potent instrument for industry, medicine, fusion, and other uses. With the aid of this technique, high-quality electron beams can be generated, which might eventually be employed to create small, portable X-ray sources. Using a linearly polarized Gaussian laser pulse, the present work focuses on examining electron acceleration in an under-dense plasma having a ramp profile with different density-hill widths. Two-dimensional Fourier–Bessel

Particle-In-Cell simulation (2D-FBPIC) code shows that optimizing the laser parameters and plasma density profile maximizes the energy gain and minimizes the normalized rms emittance in the x, y directions inside the plasma bubble. For 10 and 90 μμm density-hill widths, respectively, the optimal emittance value is reported to be ϵx~3.10 mm.mrad in the x-direction and ϵy~2.63 mm.mrad in the y-direction. At a density-hill width of 90 μμm, it is also observed that the charge trapped inside the bubble is 44.91 pC. With this density-hill width and a plasma channel length of 3.84 mm, our simulation findings show an energy gain of 0.38 GeV to the electron-bunch accelerated inside the bubble.

11. IFEL electron acceleration due to two laser pulses incident at an oblique angle Summary: The vacuum laser acceleration scheme IFEL has been investigated. We have studied the best conditions for achieving higher energy gain using two laser pulses crossing at an angle in the presence of an undulator. A group of optimized variables for electrons and the laser pulse are employed to numerically investigate the phenomena of the crossing of two lasers using the inverse free electron acceleration (IFELA) mechanism. IFELA mechanism is used to produce a high quality, micro-bunched accelerated electron beam that is used to feed a Compton scattering interaction point, which produce x-rays of directional narrow bandwidth. The effect of linear frequency chirp has been investigated and shown that the final electron energy in the presence of an undulator is strongly dependent on different parameters like the laser's initial intensity, the crossing angle between the lasers, wiggler magnetic field

strength, and the chirping of the laser pulse. It shows that the crossing of lasers plays a crucial role in the final energy gain as compared to the co-propagating lasers. The proportionality of the final energy gain on pre-accelerated electron's energy is also investigated. Hundreds of MeV energy gain has been obtained in the investigation. Currently these types of lasers are used in scientific research in the field of material science, Chemical engineering, medical science, biophysics, surface studies and solid state physics etc.

12. Tailoring Bi1–x–yBaxFeyFeO3 for desired properties: insights into structural, dielectric, and magnetic responses

Summary: In present study, samples of Bi1–x–yBaxFeyFeO3 have been synthesized, where x = 0.15, y = 0; x = 0.10, y = 0.10; and x = 0.15, y = 0.10 utilizing a swift two- stage solid-state reaction method. X-ray diffraction (XRD) data has been Rietveld refined to evaluate the structural parameters. Micro-strain is also calculated using Williamson Hall method. Temperature (300 K to 660 K) dependent measurements of the dielectric constant have been conducted at various frequencies (100 kHz, 500 kHz, and 1000 kHz). The dielectric constant (ε′) rises as the temperature increases. Two dielectric anomalies around 450 K and 613 K have been noticed in ε′ versus T curves for all the samples which might be related with defect dipoles and the magnetic transition respectively. Further, an insignificant value of loss tangent (0.2) specifically at around 300 K is a signal of small leakage current in the samples. The source of high dielectric constant is discussed by considering the structural distortions in the ceramics. A clear hysteresis

loop has been observed for all the samples which is a sign of collapse of antiferromagnetic nature of BiFeO3. Further, in case of co-doped samples, almost a saturation in magnetization with magnetization value 5.9718 emu g^{-1} has been noticed in hysteresis curve indicating a major contribution of ferromagnetic interaction. Enhancement in the net magnetization is briefly discussed by considering the ferromagnetic type direct interaction among Fe^{3+} ions and suppressing the anti-ferromagnetic type super exchange interaction.

13. Effect of isothermal annealing on the bimetallic gold-silver nanoparticles synthesized by sequential implantation in quartz matrices and their surface plasmon resonance properties

Summary: Gold-silver (AuAg) nanoparticles (NPs) of varying compositions are formed in quartz substrates by sequential implantation. The implanted samples are isothermally annealed in air at 700 °C for increasing time intervals from 0 h to 4 h. The nanostructure evolved upon annealing the implantation formed NPs in the air environment is investigated by high–angle angular dark field (HAADF) contrast imaging in scanning transmission electron microscopy (STEM) mode, which confirms the formation of crystalline alloy NPs. Rutherford Backscattering spectrometry (RBS) analysis of the annealed Au60Ag40 (numbers in subscripts show % atomic concentration of elements) films reveals two stages of compositional transformations with time. Ag concentration initially drops for 2 h and then, increases with time, while Au concentration remains almost nearly comparable. Particles grow in size with time, initially, diffusion-limited

cluster growth, and then, coarsening by Ostwald ripening. Implantation-formed AuAg NPs exhibit tunable Surface Plasmon Resonance (SPR) wavelengths from 528 nm (pure Au) and 415 nm (pure Ag) through compositional changes. The first two hours of annealing lead to a red shift in the SPR peak of Au-rich samples and a blue shift in those Ag-rich samples. However, these films show a blue-shifted SPR peak when annealed for 4 h.

14. A review on the effect of residual stresses in incremental sheet metal forming used in automotive and medical sectors

Summary: Incremental sheet forming (ISF) is a process that can produce sheet metal components with a series of stepwise small incremental deformation. This literature paper presents a thorough review of analyzing the influence of residual stresses in correlation with different process variables like tool diameter, tool path, the thickness of the sheet, depth of cut and wall angle, etc., during the procedure of single point incremental forming used in the automotive and medical industry. Moreover, this paper clearly explains the process parameters, which further help improve the ISF process compared to other conventional metal forming processes. This review initiates with the introduction of ISF for different types of materials and follows the residual stress measurement in various sectors. This paper also provides specific insights into the impact of residual stresses on forming forces, geometric shape accuracy, formability, and other factors in the process. The gap from this intensive review will provide the groundwork for the investigators for future research to recognize the implication of

residual stresses in the automotive and medical fields. Based on the investigation, residual stresses should be considered in the design step of the manufacturing process with diverse scales. Finally, the future scope and probable research directions were discussed.

15. Reliability Prediction and Its Simulation for a Friction Stir Processing Tool

Summary: Reliability estimation plays an important role in planning and implementation of condition-based proactive maintenance program and proposed the method which would help to reduce the losses in productivity. Approximate reliability of any system can be estimated easily with the help of trend exploration method. In this paper, stochastic Markov technique is used to evaluate the reliability of a high-speed steel tool which was used in friction stir processing of an aluminum alloy. This tool was used on the vertical machining center for the friction stir processing at high rotational speed. The probe wear of the tool after every pass over the workpiece was recorded for constant feed, speed, and depth of cut till the failure of the tool. Differential equations are generated based on Markov model for various failure stages and solved using Runge– Kutta method on MATLAB. This result is verified by Monte-Carlo simulation technique.

16. A study on microstructural behaviour and mechanical properties of composites febricated by friction stir processing

Summary: Being a green manufacturing technique, FSP could be viewed as the most important advancement in the field of metal joining and composite fabrication. In the

current scenario, it is required for any production technique that,it should be efficient, versatile and environment friendly. Nowadays surface composites are the most suitable materials for industrial purposes and for its fabrication, the most evolving production technique is FSP. Surface properties can be enhanced by using this technique such as strength, hardness, corrosion resistance, ductility, abrasion wear, formability, fatigue etc. Earlier, it was used to fabricate the composite of mainly aluminium and magnesium- based alloys, but now this technique can be used on steel, titanium, and other metal alloys also. Nowadays various research has been going on in the field of metal foam fabrication which is fabricated by mixing the base material with the blowing agents and the surface properties of the metal foam is better than the surface composites in term of hardness, strength, fatigue life, etc. The current review has classified to discuss the effect of the process parameters, geometry and material of the tool, reinforced particles, microstructural behavior and surface properties of the composites and metal foam

17. Fabrication of aluminium MMCs & associated difficulties – A review

Summary: Aluminium metal matrix composites are the materials of choice in every sector including aerospace, automobile, marine, military, etc. This is due to the flexibility of the fabrication methods and matrix materials to allow for the use of different types and size of reinforcement particles. The choice can be made as per the characteristic of the composite desirable for the application. This paper reviews some investigations reported in the field of composite fabrication by different methods and

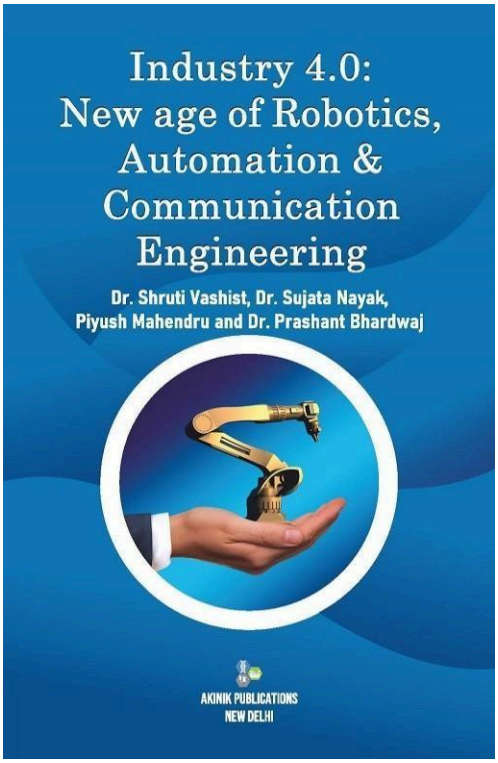
the modifications adopted in the existing methods for reducing the defects in the fabricated composites. The paper also discusses the problems encountered in the fabrication of composites and the limitations of existing methods for their suitability in commercial use. Few areas of research in the field of composites that are still not explored are also detailed which need significant attention before the use of composites in full swing as a replacement of aluminium and its alloys.

3. Book/Book-Chapter

1. Industry 4.0: New age of Robotics, Automation & Communication Engineering

Shruti Vashist, Sujata Nayak, Piyush Mahendru & Prashant Bhardwaj

Summary: "Industry 4.0: New Age of Robotics, Automation & Communication Engineering" explores the transformative impact of advanced technologies like robotics, automation, and communication systems on modern industrial practices. The book provides an in-depth analysis of how these innovations are reshaping industries, driving productivity, and fostering the integration of smart manufacturing. It offers a comprehensive understanding of the core principles behind Industry 4.0, while addressing its challenges and future prospects in global industrial settings.

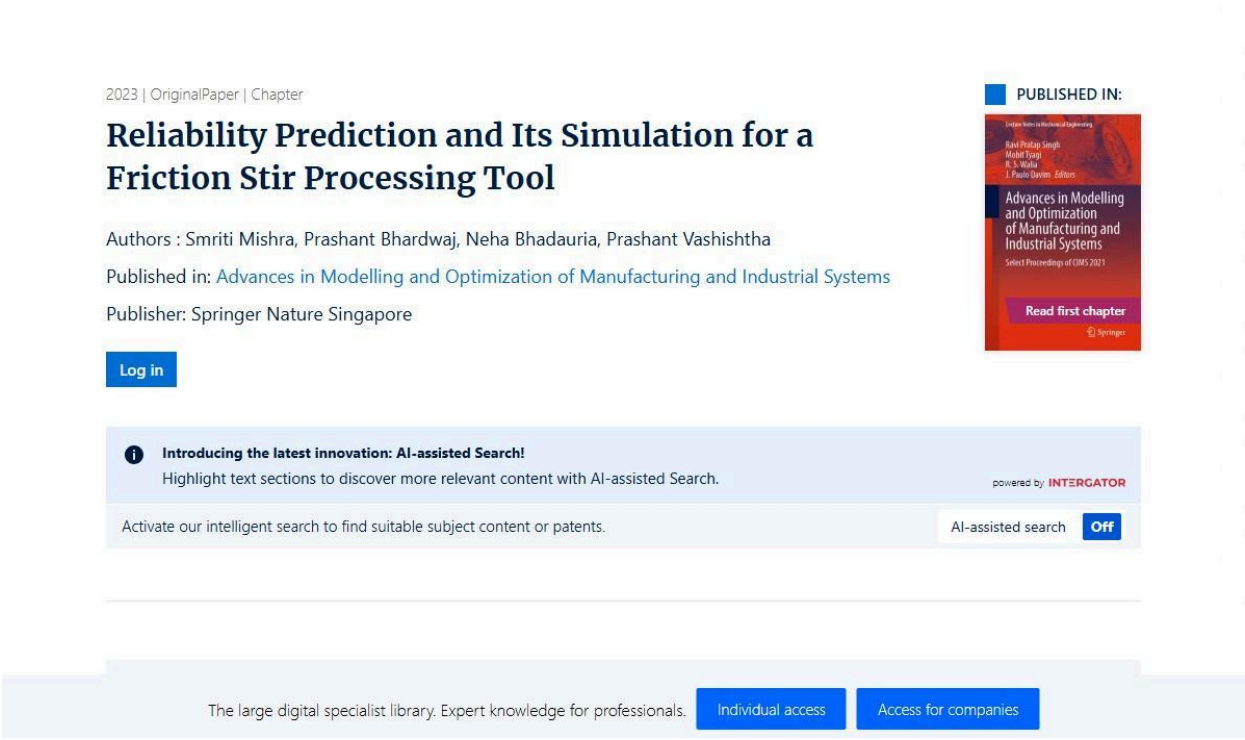


2. Reliability Prediction and Its Simulation for a Friction Stir Processing Tool

Smriti Mishra, Prashant Bhardwaj, Neha Bhadauria & Prashant Vashishtha

Summary: Reliability estimation plays an important role in planning and implementation of condition-based proactive maintenance program and proposed the method which would help to reduce the losses in productivity. Approximate reliability of any system can be estimated easily with the help of trend exploration method. In this paper, stochastic Markov technique is used to evaluate the reliability of a high-speed steel tool which was used in friction stir processing of an aluminum alloy. This tool was used on the vertical machining center for the friction stir processing at high rotational speed. The probe wear of the tool after every pass over the workpiece was recorded for constant feed, speed, and depth of cut till the failure of the tool. Differential equations

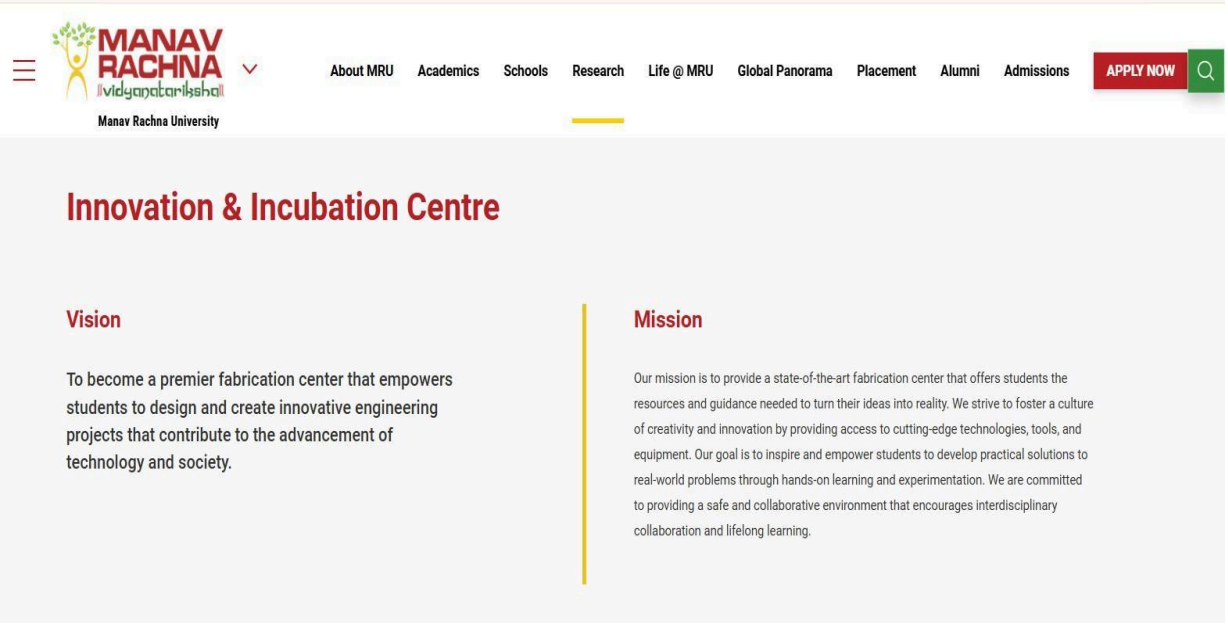
are generated based on Markov model for various failure stages and solved using Runge–Kutta method on MATLAB. This result is verified by Monte-Carlo simulation technique.



4. Institution Innovation Council

The Ministry of Education (MoE), through the MoE's Innovation Cell (MIC), introduced the Institution's Innovation Council (IIC) initiative in partnership with AICTE for Higher Educational Institutions (HEIs). Within the IIC framework, MRIIC engages a large number of faculty, students, and staff in various innovation and

entrepreneurship-related activities such as ideation, problem solving, proof-of-concept development, design thinking, intellectual property rights, project handling and management at the pre- incubation/incubation stage, and so on, to improve the MRIIRS innovation and entrepreneurship ecosystem.



https://manavrachna.edu.in/mru/research/innovation

Institution Innovation Council (IIC)
Innovation Incubation Centre, Manav Rachna University

MRU Institute Innovation Council established on 21st November 2018 in HB-01, H Block of University Campus in support of Ministry of Innovation Cell (MIC) of MHRD-AICTE has been receiving **4 star rating** continuously for the year 2019, 2020 & 2021.

Over last four years IIC of MRU has grown in terms of faculty strength and students' strength as IIC moved through its journey of IIC 1.0, IIC 2.0, IIC 3.0, IIC 4.0 to IIC 5.0. IIC MRU started with three faculty members with IIC 1.0 with each faculty member from each Engineering department of MRU which has grown to 14 faculty members today in IIC 5.0 with faculty members from various departments across the University to promote entrepreneurship and startups (maturing innovative ideas from PoC to Prototype to market ready product for a startup).

MRU IIC students won prizes in Smart India Hackathon (SIH) 2019, 2020 and also in Singapore India Hackathon 2019



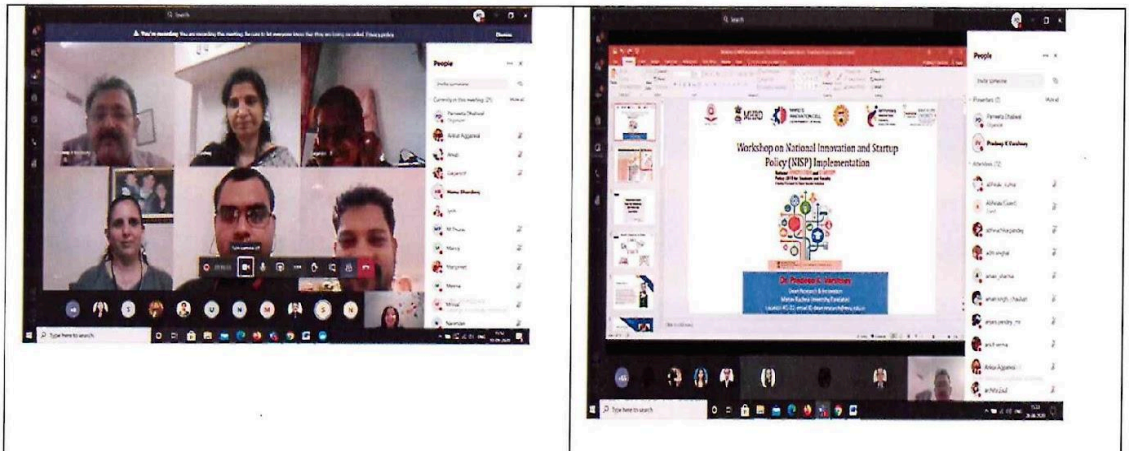
Diversified representation in the IIC established at the institute from industry, Interdisciplinary& Departments/ Units etc.

From IIC 1.0, there was diversified representation of faculty members from different engineering department to develop ideas to PoC to Prototype which are multidisciplinary. MRU IIC had external members from industry as Mentors who are associated with CoEs. IIC also has external member from banking sector. To make it more diversified, faculty members from Management

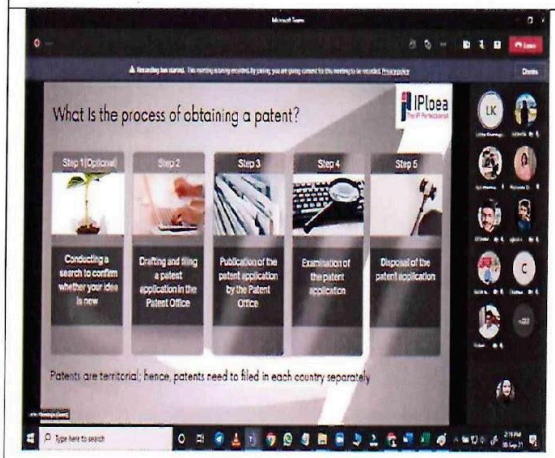
Glimpses of Event

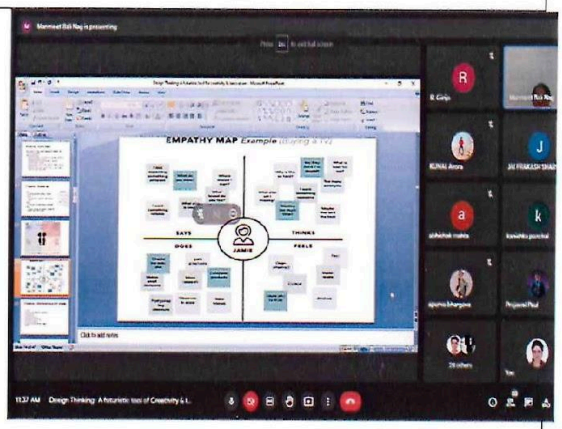
Global Startup & Entrepreneurship Conclave- 24 February, 2023

MANAV RACHNA UNIVERSITY



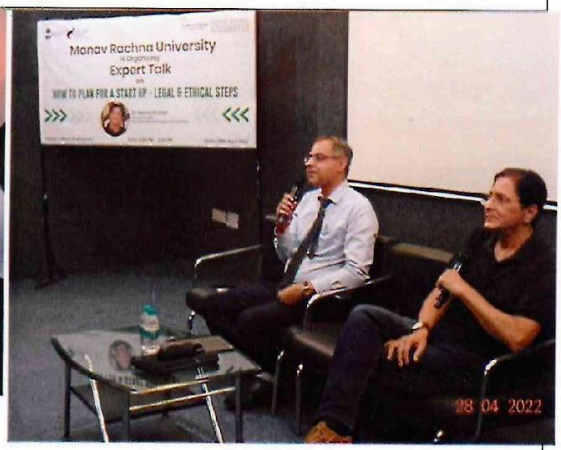

MHRD
E-CELL
WEBINAR
Design Thinking- A futuristic tool of Creativity & Innovation
Speaker
DR. MANMEET BALI NAG
Associate Professor,
Department of Management and Commerce,
Manav Rachna University
DATE
23 Feb 2022
TIME
11AM - 12 Noon
Registration link:
https://tinyurl.com/ycknbnyz
Session Link:
meet.google.com/sgt-bfga-efc
ecellmru


What Is the process of obtaining a patent?
Step 1(Optional)
Step 2
Step 3
Step 4
Step 5
Conducting a search to confirm whether your idea is new
Drafting and filing a patent application in the Patent Office
Publication of the patent application by the Patent Office
Examination of the patent application
Disposal of the patent application
Patents are territorial; hence, patents need to filed in each country separately


EMPATHY MAP


AVISHKAR 2022
15 03 2022


AVISHKAR 2022


Manav Rachna University
Expert Talk
28 04 2022


MANAV RACHNA UNIVERSITY
Workshop
on
Lean Start up& Minimum Viable Product (Business)
Guest speaker: Dr. Bindu Agarwal
Startup Mentor, Educator, Consultant and Visionary
Date of Event: 29.08.2022
Venue: IIC cell, H Block Basement
Time: 11:00 AM
Registration Link: https://forms.gle/JPJVbYsNiAgZeyUp9


Empowering Grassroot Startups for Sustainable Development
Creating employment through entrepreneurship

5. Student Faculty Projects

The B.Tech students have worked on a range of major and minor innovative projects focused on nanomaterials, space technology, and computational simulations. Projects include developing simulation software for satellite motion, synthesizing and characterizing metal-incorporated carbon soot particles (Fe and Cu) for improved properties, and studying the confined energy states of CdSe quantum dots for optoelectronics. They have also employed X-ray diffraction (XRD) to determine the lattice parameters of Fe and silver nanoparticles, enhancing understanding of their structural properties for applications in nanotechnology, catalysis, and materials science. These projects reflect a strong emphasis on practical applications in advanced technology and materials research.

Minor Projects

1. A simulation software for the motion of satellites
2. Synthesis and characterization of Fe incorporated carbon soot particle
3. Calculation of confined energy states in CdSe quantum dots
4. Synthesis and characterization of Copper incorporated carbon soot particle
5. Precise determination of lattice parameter of Fe nanoparticles using XRD studies
6. Structural investigation of silver nanoparticles using XRD studies Major Project

Include projects that promote interdisciplinary research, especially in areas like

nanotechnology, renewable energy systems, and smart materials, which contribute to sustainable infrastructure and industry.

Synthesis and Characterization Techniques

Course promotes advanced problem-solving skills related to Clean water, energy harwesting, Advanced materials synthesis, and a deeper understanding of complex physical systems, contributing to students' preparedness for higher education and research careers.