KSR INSTITUTE FOR ENGINEERING AND TECHNOLOGY

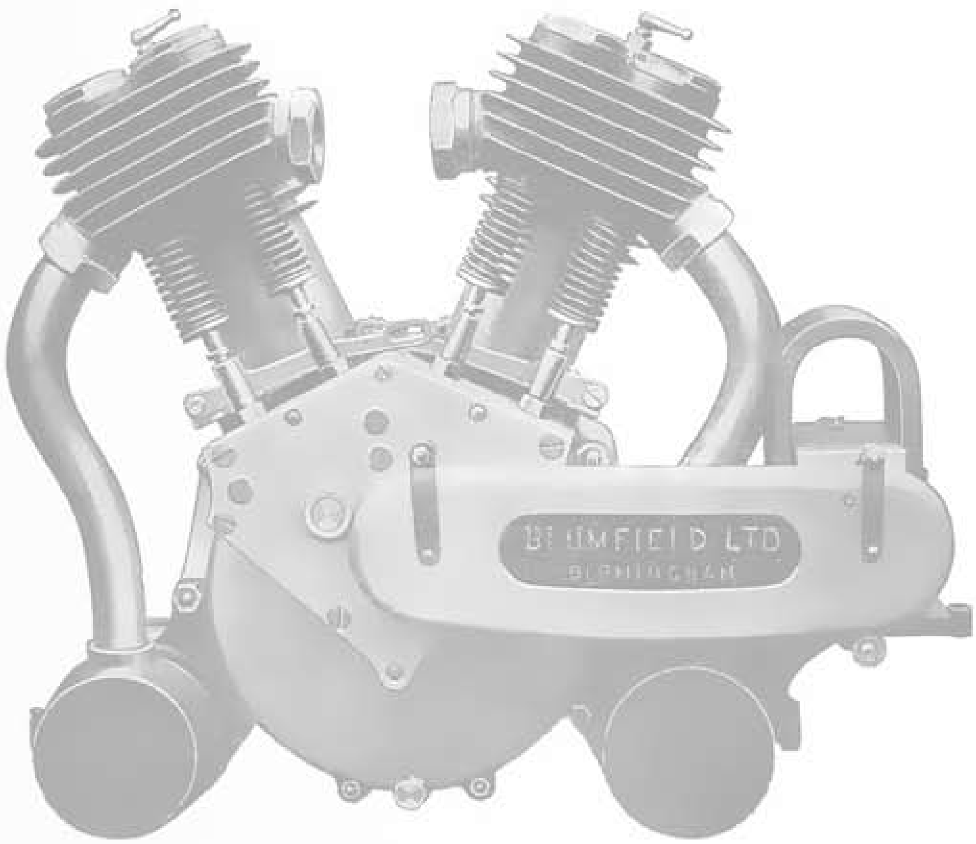
THE DEPARTMENT MAGAZINE

Department of Mechanical Engineering

MECH ZINE

VOLUME 3 ISSUE 1

The Gear of Tomorrow



If its broken, take it apart and fix it.

ACADEMIC YEAR 2016 - 2017

KSR INSTITUTE FOR ENGINEERING AND TECHNOLOGY

Vision

To become a globally recognized Institution in Engineering Education, Research and Entrepreneurship.

Mission

IM1	Accomplish quality education through improved teaching learning process
IM2	Enrich technical skills with state of the art laboratories and facilities
IM3	Enhance research and entrepreneurship activities to meet the industrial and societal needs

DEPARTMENT OF MECHANICAL ENGINEERING

Vision

To produce globally recognized Mechanical Engineers and Entrepreneurs to meet the industrial challenges with ethical values.

Mission

DM1	Impart quality education in Mechanical Engineering through enhanced teaching learning process.
DM2	Provide platform to apply and analyze the engineering concepts with state of the art laboratories.
DM3	Augment the technical knowledge among students and faculty members through research activities to meet industrial and societal needs.

Program Educational Objectives (PEOs)

PEOs	Keywords	Description
PEO1	**Core Competency**	Graduates will adopt technological changes in core and allied areas of Mechanical Engineering.
PEO2	**Professionalism**	Graduates will have leadership quality with soft skills to excel in their professional career.
PEO3	**Higher Studies and Entrepreneurship**	Graduates will evoke interest in higher education and develop entrepreneurial attitude for ever changing industrial and societal environment.

MECHZINE

Plasma Actuator Tip Flow Control

P. Manikandan, II Year, Department of Mechanical Engineering, KSRIET

This GE study represents the first open literature report of plasma actuators actually used on gas turbine blading at representative engine flow conditions. The exact mechanisms of interaction between weakly ionized gas and neutral air are still under study; however, the collisional processes between them are responsible for the momentum transfer causing the plasma actuator flow. Tip clearance effects are especially critical in gas turbine high-pressure compressors, where they are a large source of aerodynamic loss and stall inducing blockage. In the Dusseldorf discussion on the GE paper, it has been reported that the electronics associated with dielectric barrier discharge (DBD) are continuously being improved and miniaturized. Voltages needed are being reduced, and there is an unexplored area involving the great operational flexibility offered by frequency control. Given the flexible and superior response time of modern electronics, it should be possible to adjust DBD operation in response to transient flow phenomena associated with blade passing frequency.

Axial flow turbomachinery tip leakage, be it at the tip of a rotating blade or at the root of a cantilevered stator represents an insidious source of aerodynamic loss in gas turbines, decreasing component efficiencies in both compressors and turbines.

I wrote about tip clearance and its control in an earlier article. Tightening tip clearances and keeping them under control is a constant worry for OEMs and operators. Two critical parameters for tip leakage flows are the airfoil loading (local pressure difference between pressure and suction surfaces) and the actual tip clearance (either expressed as a percentage of span or chord). Loading is set by the designer and tip clearance is the stepchild to be controlled.

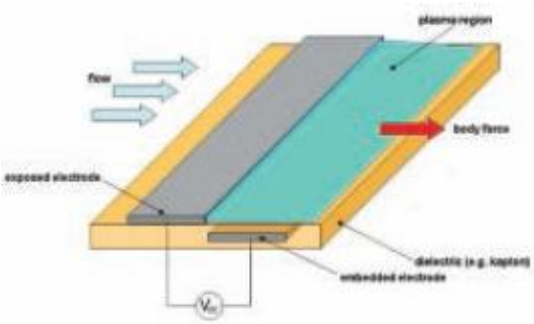
Tip clearance effects are especially critical in gas turbine high pressure compressors, where they are a large source of aerodynamic loss and stall inducing blockage. According to Saddoughi, , due to low aspect ratio blading and mechanical limitations on the actual magnitude of achievable clearances, new high compressor designs are forced to accept tip gaps from 1% to 4% (based on span). This has a significant impact in reducing high compressor efficiency and stall margins, in these very low aspect ratio blade passages.

In our June -20, 20 TURBO EXPO in Dusseldorf, Aspi Wadia of GE Aviation, a co-author of , presented promising results from an experimental evaluation of the impact of high compressor tip clearance with and without plasma actuator flow control. The evaluation was run on the Law/Wennerstrom single-stage transonic compressor rig at Wright Patterson AFB in Ohio.

The plasma actuators were placed on the compressor's casing inner wall upstream of the rotor leading edge. The compressor performance was mapped from part-speed to high speed at three clearances with axial and skewed configurations of the plasma actuators at six different actuator frequency levels. The authors report a maximum stall margin improvement of 4%, with the large clearance configuration benefiting the most. They attribute the improvement by plasma actuators to a reduction in unsteadiness of the tip clearance vortex under near stall conditions. No impact was seen in compressor steady state performance. This GE study represents the first open literature report of plasma actuators actually used on gas turbine blading at representative engine flow conditions. Past studies have dealt with wind tunnel tests on flat plates and plane cascades, usually with subsonic flows at lower Reynolds numbers.

Just what is a plasma actuator? There are a number of versions, but the most popular is the dielectric barrir discharge (DBD) plasma actuator. The DBD version was used in the GE study [2] reported on in Dusseldorf by Wadia, and is shown in sketch of Fig. 1.

Figure 1 Dielectric Barrier Discharge Plasma Actuator



Following an explanation given by Kotsonis, et al , DBD is based on the ionization of air using an ac voltage between two electrodes, as shown in Figure. The electrodes are separated by a dielectric barrier layer (e.g., a Kapton polyimide film) which prohibits arc formation, but allows accumulation of ionized gas in the vicinity of the exposed electrode end.

The ionized gas is acted upon by a Lorentz force (the body force in Fig. 1), and will cause it to flow concurrently away from the edge of the exposed electrode. The exact mechanisms of interaction between weakly ionized gas and neutral air are still under study , but the collisional processes between them are responsible for the momentum transfer causing the plasma actuator flow.

Ideally, DBDs would be mounted on a compressor (or turbine) casing inner wall circumferentially and axially in the blade path. The induced Lorentz forces then oppose the pressure gradient forces which cause tip leakage. It is important to point out that the resultant Lorentz force is a function of both DBD applied voltage and the ac frequency, thus allowing two ways to control tip leakage. Given the flexible and superior response time of modern electronics, it should be possible to adjust DBD operation in response to transient flow phenomena associated with blade passing frequency.

In the Dusseldorf discussion on the GE paper , Wadia reported that the electronics associated with DBD are continuously being improved and miniaturized. Voltages needed are being reduced, and there is an unexplored area involving the great operational flexibility offered by frequency control. Readers should keep eyes open for future developments in this potentially important area of tip leakage control.

Jet Engine Fuel Burn Reduction Through Boundary Layer Ingestion

P.R. Manoj Kumar, II Year, Department of Mechanical Engineering, KSRIET

This article explains various technical aspects of the boundary layer ingestion (BLI) concept. Using BLI, airliner designs featuring close-coupled, rear-mounted turbofans are being considered, with a fuselage sculpted to sweep a large part of the fuselage boundary layer into engine inlets for reduced fuel consumption. With an engine array fuselage-centered, rather than splayed out on wings, reduced rudder control is needed in the event of a single engine outage. This reduces the size of a BLI tail assembly, saving weight and reducing drag. A near-future goal of the BLI studies is to determine if modern engine front-mounted fans can be designed to operate efficiently and stably under BLI inlet conditions. The D8 design is aimed at the huge single-aisle, narrow-body market, now dominated by the Boeing 737 and Airbus 320 families. Airframe and engine designers strive to achieve 'clean' inlet flow conditions for jet engines.

In their frontal engine location, fans and compressors work best with a uniform flow, free of significant total pressure losses. The famous S-shaped inlet duct for the middle engine of Boeing's tri-jet 727 required a lot of engineering attention to minimize inlet distortion for happy engine operation.

However, airline fuel costs have become such a major driving factor, the need for clean inlet flow conditions is being re-evaluated. Using a concept called "boundary layer ingestion" (BLI), airliner designs featuring close-coupled, rear-mounted turbofans are being considered, with a fuselage sculpted to sweep a large part of the fuselage boundary layer into engine inlets for reduced fuel consumption. (Recall that Ludwig Prandtl's boundary layer consists of viscously retarded fluid flow near and in contact with a solid surface, that is a source of aircraft frictional drag.)

With an engine array fuselage-centered, rather than splayed out on wings, reduced rudder control is needed in the event of a single engine outage. This reduces the size of a BLI tail assembly, saving weight and reducing drag.

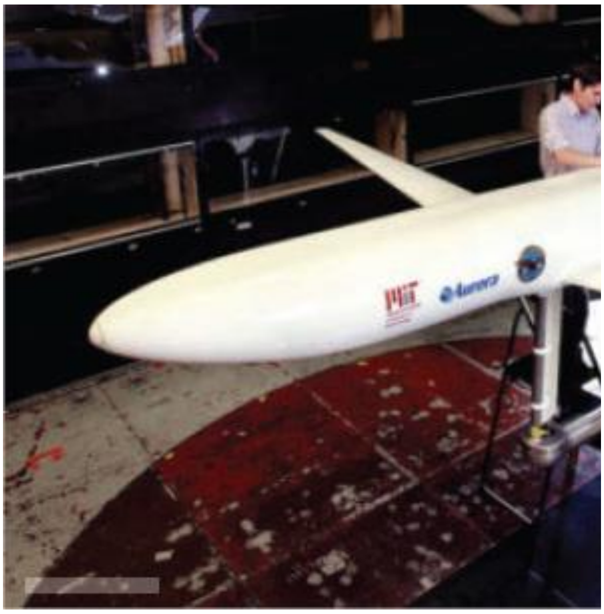
Just how could the ingestion of the slackened and distorted flow of a boundary layer reduce engine fuel consumption? Given a flight speed of u_0 , the average air velocity entering a BLI engine would be $u_1 < u_0$ where the magnitude of u1 would depend on the extent of the ingested boundary layer. Following a simplified model by Plas [1], consider an idealized one-dimensional flow entering a BLI jet engine at u_1, and leaving the engine nozzle at u_2. The thrust force, T, created by the engine is:

$$(1)\; T = \dot{m}(u_2 - u_1) = \dot{m}\,\Delta u$$

given by the momentum equation in the axial direction for the engine as the control volume. The mass flow of air through the engine is $\dot{m}$

and we have neglected the small effect of fuel flow.

Figure 1 MIT's Mark Drela (right) and Alejandra Uranga prepare the D8 model for NASA wind tunnel testing. (Aviation Week and Space Technology)



The mechanical power, P, produced by the engine flow is equal to the rate of change of its kinetic energy, given by:

$$P=\dot{m}2(u22-u21)=T(u1+u22)=T(u1+\Delta u2)$$

If we assume the BLI engine will have a the same mass flow, $\dot{m}$

, and a thrust force, T, as the conventional engine, Δu in will be a constant. A decrease in the average velocity u_1 entering the engine will thus result in a decrease in power P — and consequently the promise of reduced engine fuel consumption.

In a paper on wake ingestion, Smith points out it has been long known in the field of marine propulsion, that ingestion of craft wakes (surface ships, torpedoes or submarines) in a propeller can reduce the propulsive power needed. He points out that Albert Betz (a student of Prandtl) explains that with wake ingestion the power expended can actually be less than the product of the forward speed and craft drag.

Recently, an Aviation Week and Space Technology article highlights research going on at Massachusetts Institute of Technology (MIT), NASA, Aurora Flight Sciences, Pratt & Whitney and United Technologies Research Center to evaluate BLI.

Late last year, tests were carried out at the NASA ' x 22' wind tunnel at Langley Research Centre, VA. by the BLI team (the first three of the above organizations). Their D8 configuration test model shown in Fig. 1, was designed by Prof. Mark Drela. It departs from the traditional cylindrical tube and wing shape, to provide more fuselage lift with a roughly elliptical cross section. (Current literature frequently refers to it as a "double bubble" shape. As an early bubble experimentalist, I would comment its cross section is similar to a single non-spherical large bubble rising in a liquid, flattened on the bottom and with more curvature on the top.)

The D8 design is aimed at the huge single-aisle, narrow body market, now dominated by the Boeing 737 and Airbus 320 families. Both Boeing and Airbus are projecting this as a two trillion dollar (US) market for the next 20 years, accounting for more than 23,000 airplane deliveries. (Because of its greater fuselage width, the D8 design with twin aisles would modify the market designation.)

The project's principal investigator is MIT's Prof. Edward Greitzer who is also a past chair of the IGTI Board of Directors. Two goals of the test are to validate the BLI benefit and characterize the flow into aft-mounted propulsors. Both BLI and conventionally podded propulsors were tested, using electrically driven fans. The BLI aerodynamic benefit is determined by comparing the mechanical power produced by the fans in each configuration at cruise conditions, defined as zero net force on the model as determined by the wind tunnel force balance. Preliminary data shows promising power savings of 5 to 8 percent for the aerodynamic effects of the D8 integrated configuration , with an estimated 18 percent gain including aircraft systems benefits.

A near-future goal of the BLI studies is to determine if modern engine front-mounted fans can be designed to operate efficiently and stably under BLI inlet conditions. Stay tuned - I'm sure there will be more to come on the promise of BLI.

Aviation, Gas Turbines and the 'Three Worlds'

S.C. Surya, II Year, Department of Mechanical Engineering, KSRIET

In the aviation industry, the safety of the people who fly is directly linked to the decisions that are made by the employees of the organizations that produce the airplanes and engines that power them. As a member of such an organization, Mr. Herzner experienced the gravity of making such decisions when he was involved with an airplane accident where 1 people lost their lives. That experience caused him to reflect on how and why such decisions get made. He drew some important conclusions and used them to formulate recommendations on how to make decisions which avoid such devastating consequences.

However when several recent very big events involving large organizations came into the news, he used them to benchmark his recommendations. What he found was several of those event involved unethical behavior. That was an eye-opener because he had never been involved with such behavior. That led him to modify his perspective on how decisions get made.

Using all of that, Mr. Herzner describes the principles that influence how decisions get made and makes recommendations on how organizations and the people in them can avoid what he calls the 'doomsday event".

During my 38 year career at GE Aircraft Engines, I was privileged to have had the opportunity to work on a variety of projects ranging from advanced technology demonstrator engines, military bomber and fighter engines and commercial engines for many of the world's commercial airplanes. It doesn't get better than that for a person who has been fascinated with airplanes and aviation for his entire life. In addition to that, I worked for a good company which considered safety and reliability as being their underlying value. Then on July 1, 18, a DC- powered by CF6-6 engines crashed in Sioux City Iowa killing 1 passengers. At the time of the accident, I was the engineering manager responsible for the CF6 engine product line.

The post-accident investigation revealed that the event 48 was initiated by the failure of the fan disc which was at the front of the engine mounted in the tail of the three engine DC-. That failure released high energy debris which breached all three hydraulic lines running through the horizontal stabilizer of the airplane. That loss of hydraulic pressure made the aircraft essentially uncontrollable and, in spite of heroic efforts by the crew, the airplane crash landed in Sioux City.

That accident was a life changing event for many people especially the victims and their families. However, what I didn't expect was that it was life changing for me as well. Why? Because a number of years before the accident, I was working on a problem which was eventually proven to have been the initiator of the event. Not only that, in retrospect, I concluded that I had made a decision which, had it been different, may have prevented the accident. I was devastated!

I was particularly focused on what I knew and what I did preceding the event. I drew a number of conclusions and, when I became Chief Engineer, instituted a company policy based on those conclusions addressing how we made product safety decisions. That policy is essentially the same as the one GE Aviation uses today.

Figure 1. DC- Engine Configuration

Following my retirement in 2002, I watched as a number of really big/bad events happened which involved large organizations. Specifically those events were the BP oil spill into the Gulf of Mexico and the GM ignition switch problem. They not only involved a loss of life but had huge financial and reputation consequences for BP and GM. I immediately looked into them and had the thought that, if those organizations had the benefit of what I had concluded about the Sioux City DC event, those events might have been prevented.

Then two other huge events involving large organizations happened. They were the Flint Michigan lead in the water and the VW Diesel emissions cheating events. But these events were very different for Sioux City, BP, or GM. Why? Because the involved unethical behavior inside the organization. That was an eye-opener for me. I could not believe that the organizations and the people in them could resort to behavior that was so egregious. That was especially true of the Flint Michigan event where the people and children of the City of Flint were supplied with lead tainted water.

All of this led me up to developing a set of “factors” which I believe influence the way people in large organizations make decisions. They are:

- Values
- Goals
- Culture
- Measurements
- Perception of Risk
- Organizational Complexity

Based on these “influence factors” I developed a set of principles which I believe give guidance to those in organizations which are involved in projects which might result in disastrous consequences for the users and the creators of the products involved. These principles are:

- Clearly communicate the values of the enterprise
- Build and nurture the "right" culture
- Always get diverse input when making critical decisions
- Trust but Verify
- The "logo" is responsible so the "logo" should make the decision
- Define individual roles and responsibilities

Well, how does all this relate to aviation, gas turbines, and the "three worlds"? First of all, I believe that the aviation environment (and especially commercial aviation) is different in that the lives of the passengers and crew are immediately and directly linked to the proper functioning of both the aircraft and the engines powering them. The expectation of the "outside world" (the passengers, the future traveler, the governments, the media, the regulators, etc.) is absolute. A safe flight is assumed! The corporation (the second "world" - I use the term "logo") will be held responsible for their actions both technically and ethically! But, the organization is made up of people! You as members of the organization dictate what the organization does. This then brings up the "third world". You are members of, not only the "corporate world", but of the "personal world". I can tell you from personal experience that, should you be involved in a catastrophic event and if you are a responsible and moral individual, you will judge yourself on what you knew and what you did prior to its happening.

Let me leave you with these thoughts. The aviation business is the "Yankee Stadium" of businesses. It is the most responsible, most technically advanced, and involves huge amounts of money. It is only a place where the best, the brightest, and the most responsible people ought to be. It is also a place where there are risks and risks have to be managed. That means decisions have to be made. Making those decisions is never easy. If you are lucky enough to be involved in this business, always do the best job that you can. That is what is expected of all of us. And, should the "doomsday event" occur, that is what you will have expected of yourself.

If you would like to read more about the topic of making decisions in large organizations, I have a book out on Amazon called *What Did We Know? What Did We Do?*

1. Herzner, Fred, 2017, *What Did We Know? What Did We Do?*, Smart Business Network.

Advanced Manufacturing is changing the ways that many companies do business, as it has been proven to reduce lead time and cost while enhancing performance and innovation. This 2-day symposium brings together engineers, designers, researchers, repair professionals and business leaders at companies that design, manufacture, repair and own gas turbines to:

- Gain knowledge of the latest design strategies for additive-built parts and repair techniques from renowned experts:
  - **Timothy W. Simpson, Ph.D.,** Pennsylvania State University and Center for Innovative Materials Processing through Direct Digital Deposition (CIMP-3D)
  - **Bernd Burbaum, Andreas Graichen,** Siemens
- Experience innovative technologies by the leading companies leveraging advanced manufacturing.
- Be part of a unique interface event between the gas turbine industry,

academia, and manufacturing & repair practitioners.

- Contextualize how advanced manufacturing is changing business models and enhancing business transformation.

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- Drive technology adoption through knowledge dissemination, workforce development, standards development, and conformity assessment solutions.
- Network with experts in advanced manufacturing for gas turbines

A new concept of vibration-control system in continuous miner machine

K.Gopinath, III Year, Department of Mechanical Engineering, KSRIET

The article reviews the technical solution applied to these machines which are currently in use worldwide. Special attention is paid to the new concept of a cutter drum powertrain system, where the permanent magnet technology motors are proposed. Placing them inside the cutting drum results in improved dynamic performance of the mining process, as well as the possibility of modular configuration depending on the required operating condition. The authors analysed the dynamics of mining in continuous miner machines, where the adverse impact of vibrations during this process was noticed. The reason for this problem is the occurrence of resonance frequencies in the structure of the machine, which significantly shortens its life time. In previous publications, approaches based on avoiding resonance and adjusted shape modes to reduce displacement of cutter drum were presented. One of the ways to achieve this effect is to control cutter drum's angular velocity. It allows thinking about a new concept of vibration-control system based on smooth speed change of the cutter drum or/and the angular speed of the boom.

Coal is still a key energy source for many countries. An increasing share of coal beds is represented by thin layers with a thickness less than 1.2 m and remnants of seams which require work on a board and pillar system. The core machines designed for this purpose must have high productivity with limited geometrical dimensions. In general, these types of roadheaders are called 'continuous miners'. The geometrical restrictions, in this case, are strongly correlated with the design form of the machines.

Continuous miners are mining machines equipped with a milling head with dimensions corresponding usually to the width of the heading or the tunnel. The milling head is usually installed on a boom, which most often performs a simple swinging motion in a vertical plane. The face is mined at the entire width of the heading. Where it is necessary to widen the heading, the miner is moved to a new position, or the cutting assembly alone is rotated in a horizontal plane to mine the subsequent beds or layers of rocks. Continuous miners are often used for the exploitation of coal and other useful minerals using room and pillar mining systems. (Prof Adam Klich and Dr Krzysztof Kotwica). Continuous miners, manufactured by companies such as Joy, Jeffrey, Sandvik, Eickhoff and Caterpillar, are used as a standard solution mostly in the American and Australian mining. Boom-type continuous miners are different to other roadheaders in terms of the method used to mill the face of the heading and thus a different milling head solution – in the form of a cylinder or a drum. Due to the vertical movement of the head from top to bottom, the application of a turn table in such types of roadheaders is usually not necessary. The continuous miners move on a heavy-tracked chassis with a loading table in the front, where the mined material is scraped towards a scraper conveyor located in the central part of the continuous miner. The scraper conveyor is equipped with an extension facilitating the transfer of the mined material to another means of haulage. A flat, extensible or non-extensible telescopic boom is mounted to the front part of the tracked chassis, at the end of which, the cylinder or drum milling head is attached. The milling head is capable of changing its width slightly by means of telescopic extensible side parts of the head.

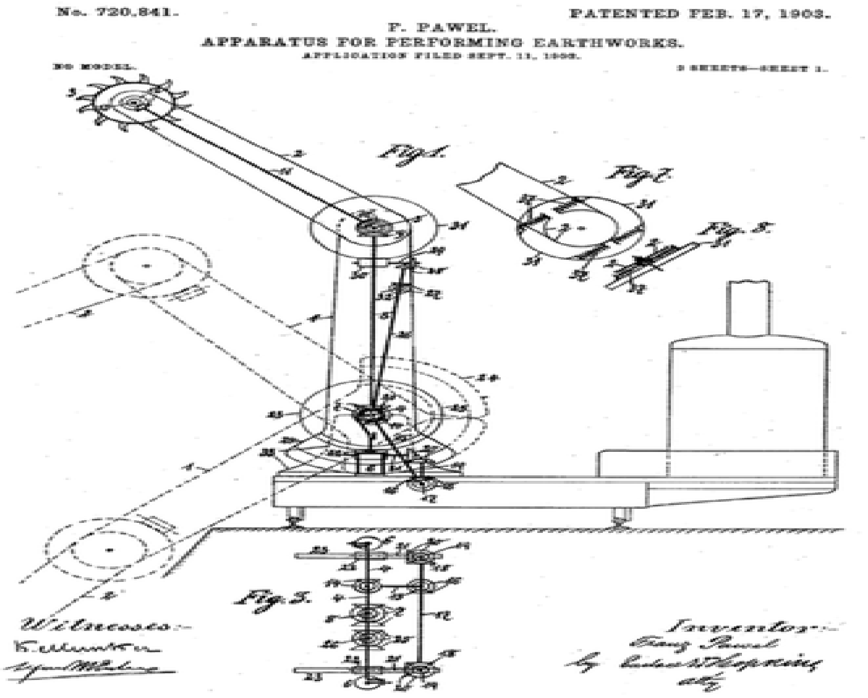
Depending on the structure of the boom, the main movement, until the full slotting of the head is reached, is conducted by means of the tracked chassis or by the extensible boom itself.

Continuous miners are equipped with a milling head of a size corresponding to the width of the heading or tunnel. The head is installed on the boom that usually performs a simple swinging motion in a vertical plane. The heading face is mined at the entire width of the heading. Where it is necessary to widen the heading, the miner is moved to a new location, or the cutting assembly alone is rotated in a horizontal plane to mine the subsequent beds or layers of rocks.

The standard solution among continuous-mining headers includes the continuous miner and bolter miner machines. These machines have numerous applications, including American and Australian mining industries, for extracting deposits of hard coal, salt, potassium or gypsum, as well as for preparatory works and tunnel drilling in stone.

The majority of continuous miner and bolter miner machines can be used in mining and geological conditions where it is possible to apply roof bolting. Due to significant costs and amount of required labour in the execution of a heading, steel arch support sets are very rarely applied.

The first constructions of this type, as well as patent claims, emerged at the turn of the 1th and 20th centuries. An example is a construction proposed by F Pawel in a patent application dated September 2 .



Decentralized control of vibrations in wind turbines using multiple active tuned mass dampers with stroke constraint

C. Vinothkumar, IV Year, Department of Mechanical Engineering, KSRIET

This article is devoted to the study of the vibration control for blades and tower in a wind turbine. Based on the Euler–Lagrangian method, a multi-body dynamic model including three blades with distributed parameter, tower, and their coupling is obtained. Multi active tuned mass dampers have been utilizing as damping devices. Therefore, the dynamics of the tuned mass dampers are also considered in modeling. The influence of extreme wind, and grid dynamics on the vibration of the blade was analyzed. Moreover, the nonlinearity induced by space constraints, which impact on vibration control, is introduced. For active control, the constrained decentralized control strategy is designed via linear matrix inequality which tuned mass dampers stroke constraints are modeled as hard constraints. A doubly fed induction generator connected to an infinite bus including the detailed electrical and structural model was performed on MATLAB/Simulink. Simulation results show that the control strategy can effectively reduce the vibration of the blade while the damper stroke satisfies the working space permitted by the blade. Investigations demonstrate promising results for decentralized constrained control in simultaneous control blade vibrations and tower vibrations. Each actuator is driven separately from the output of the corresponding sensor so that only local feedback control is achieved; this improves the system reliability.

Vibrations in wind turbines can affect the safe operation and influence on power production.[1] To reduce the impacts of vibrations, structural control is the ideal control approach for wind turbines. Due to the hollow nature of the blade and the nacelle, the damper installed inside of these components can independently on speed or power regulation. Previous work by many researchers focused on the feasible of the damping devices. The tuned mass damper which consists of a mass, spring, and damping, is the most common device in vibration control. For mitigating of a tower of the wind turbine, a passive tuned mass damper (TMD) placed on the top of the tower for reduction vibration is proposed. Lackner and Rotea modified the FAST wind turbine computer-aided engineering software tool, by incorporating two independent TMDs into the nacelle. Thus, add structural control capacity to Fatigue, Aerodynamics, Structures, and Turbulence (FAST). Implementing this modified version of FAST, Tong et al. proposed a new optimal method for designing TMD which is used to control the tower vibration. In the study of Brodersen et al., the TMD parameter estimation is conducted under different wind and wave conditions. Zuo et al.investigate applying multiple TMD to reduce offshore wind turbine vibrations under multiple hazards. For suppressing blade vibrations, there are few studies regarding structural control. The motion of the blade is more complicated than the tower. No simulation software can be used to design and simulate blade structural control. In the literature, the TMDs are used to control the blade vibrations which are mainly based on the established simplified dynamic equation. The semi-active TMDs to control edgewise vibrations is presented in Arrigan et al.In Fitzgerald et al., the authors investigated using active TMD for mitigating edgewise vibrations. It was found that the active

TMD can provide better reduction than the passive TMD. Fitzgerald and Basu extends the result by proposed a cable connected active TMD to suppress edgewise vibrations. However, these research focuses on the feasibility of dampers. The control algorithm uses simple linear optimal regulator state feedback and cannot guarantee the stroke constraints in theoretically. Nevertheless, in their design process, the nonlinearity due to space constraints is not considered. In the FAST-SC (the modified version of FASTsimulation, it has been demonstrated that the stop forces have a strong influence on vibration control. Moreover, in the model, the rotor speed is assumed as constant and does not take into account the dynamic due to the electrical dynamic. The grid-connected wind turbines often have a voltage variation in actual operation. Due to the coupling of the mechanical part and the electrical part, the electrical disturbance will affect the mechanical characteristics of the wind turbine and cause mechanical vibration. Therefore, detailed mechanical model and electrical model of wind turbines must be considered.

In a practical implementation, full knowledge of the state vector is rarely available. An available approach is an output feedback control. Meanwhile, the centralized control strategy needs a large number of sensors and communication network; this may have poor reliability. For large-scale structures, decentralized static output feedback control is a more practical approach. Solving the static output feedback with information constraints is a popular research topic. An linear matrix inequality (LMI) variable transformations were obtained and a two-step procedure is proposed to improve feasibility issues of solving LMI optimization problem. In this article, based on these fore-mentioned considerations in the existing article.’” The major contributions of this article are as follows: (1) a closed-loop -degree-of-freedom (DOF) structural model established in Fitzgerald et al. is extended to consider the grid-connected dynamic, in which the rotor speed is variable due to the change of grid voltage. Moreover, the mechano-electrical coupling model of grid-connected doubly fed induce wind turbines was developed in this article. (2) The dynamic equation established in Fitzgerald et al. is extended to modeling the TMD stroke constraint. Due to the space limitations of the blade and the nacelle, the stroke of the TMD must be limited, the stopping forces are incorporated into the model when the TMD displacement exceeds the allowable stroke. (3) A decentralized static output feedback controller was implemented, which each TMD is controlled individually by the corresponding velocity signal. To the authors’ knowledge, decentralized control of wind turbines has not been studied in existing literature. To fill this gap, the present paper explores decentralized structural control of the wind turbines with TMD subjected to wind load where the damper stroke is modeled as the constraint output. The designed controllers can be easily solved via LMI optimization problem.

Prediction and analysis of surface roughness in selective inhibition sintered high-density polyethylene parts: A parametric approach using response surface methodology–grey relational analysis

R. Sasikuamr, IV Year, Department of Mechanical Engineering, KSRIET

Selective inhibition sintering (SIS) process intends to produce near-net-shape components through sintering of specific region of powder particles. The prediction of surface quality in SIS parts is a challenging task due to its complex part building mechanism and influence of abundant process parameters. Therefore, this study investigates the key contributing parameters such as layer thickness, heater energy, heater feedrate and printer feedrate on the surface quality characteristics (R_a, R_z and R_q) of high-density polyethylene specimens fabricated through selective inhibition sintering process. The SIS system is custom built and experiments are conducted based on four-factor, three-level Box–Behnken design. The empirical models have been developed for predicting the influence of selected parameters on surface quality. The optimal process parameters such as the layer thickness of 0.1 mm, heater energy of 28.48 J/mm^2, heater feedrate of 3.25 mm/s and printer feedrate of 1 mm/min are attained using grey relational multi-criteria decision-making approach. Furthermore, response surface analysis revealed that surface quality of sintered components is influenced significantly with heater energy and heater feedrate, followed by layer thickness. The confirmation experiments based on optimal process variables validate the developed grey relational analysis strategy.

Additive manufacturing (AM) technique is widely used to fabricate the functional parts of three-dimensional (3D) computer-aided design (CAD) models without using fixtures and moulds. The parts produced using AM methodologies are used as prototypes and end-user products in the field of medical, construction, tool and die-making, and automobile industries. It offers design flexibility in the early stages of design process before commencement of mass production and enables manufacturers to fabricate functional components of complex profile. AM eliminates ill-effects such as chemical degradation of materials due to high processing temperature and abnormal shrinkage that accompanies during conventional manufacturing methods. It also reduces cavity formation because of density difference between crystalline and amorphous phases during crystallization that arises in the conventional processes such as moulding and casting. At present, there are over 20 different recognized AM techniques that are available in the market to fabricate functional prototypes.

Being capable of processing an extensive range of materials (metals, polymers, alloys and ceramics) and non-usage of support structures, selective laser sintering (SLS) is presently regarded as the most versatile AM process. In SLS process, a 3D object is developed layer by layer using a focused laser beam that selectively scans and sinters the surface of the powder bed enabling consolidation of powder particles. Due to high initial investment, and expensive operating and maintenance costs, SLS is mostly used in giant organizations such as NASA and GE to produce full density parts with high resolution. In few cases where full density is not an essential criteria, a low-cost approach such as bulk sintering is resorted. One of the ways to reduce the cost of a SLS machine is to have an alternative for laser to supply heat energy to the powders. Though elimination of laser simultaneously reduces machine cost and built time, it necessitates an alternative method for selectively sintering the particles. To overcome this issue, selective inhibition sintering (SIS) process is developed. SIS is an inexpensive process when compared to any other AM processes.

SIS produces parts from powders of polymers, ceramics and metals through fusing of powder particles to achieve sintering in the part body and inhibition at the part boundary.' Inhibitor is deposited using a print nozzle to make the part profile, and a ceramic or infrared heater is used to supply heat energy across the predetermined surface area of a layer to sinter. Due to the huge difference between melting points of inhibitor (high) and polymer powder (low), the region printed with inhibitor absorbs heat energy and therefore the powder below inhibitor will not be sintered and the remaining area will be sintered. Unlike other commercially available AM processes, SIS functions with a low-cost heating system and indigenous polymers to build parts. Compared to the existing manufacturing processes, SIS has less impact on the environment. As SIS does not use high-power lasers and cooling circuitry, carbon footprint associated with SIS is much less when compared to other laser-enabled AM processes. Despite its potential benefits, usage of SIS in real-time applications is currently limited to a few applications. This might be attributed to the scarcity of the literature to evaluate the dimensional accuracy, mechanical strength, surface quality, tribological properties and service life of the SIS-fabricated parts. The characteristics of SIS parts are inferior to those of other commercially available AM techniques. Therefore, improving these properties is essential to meet the demands of numerous applications such as automobile, armament and bio-medical fields. Improving dimensional accuracy, specimen strength, surface quality and built time is the crucial issue to be addressed for effective implementation of AM techniques.

Several investigations are carried out to enhance the quality and performance characteristics of AM parts by appropriate selection of process variables. Sood et al. considered the fused deposition modelled (FDM) specimens to investigate the compressive strength using particle swarm optimization and artificial neural network approach and stated that the compressive strength of fabricated parts is abridged due to anisotropy properties of polymers and weak interlayer bonding due to the formation of pores. Rayegani and Onwubolu conducted experiments on improving the tensile strength of FDM parts. They proposed a differential evolutionary approach to examine the tensile strength that is significantly influenced by a suitable combination of negative air gap, smaller raster width and increased raster angle. Hussain et al. conducted experiments on fabrication of Ti-based metal matrix composites using direct metal laser sintering technique through varying the process variables and reported that the powder composition had more influence on hardness and wear resistance of sintered specimens, whereas laser energy had significant effect on part density. They concluded that the laser energy, scanning speed and layer thickness are most influencing the shrinkage of parts in Z-direction. Fahad and Hopkinson performed the comparative evaluation of geometrical accuracy (flatness and squareness) of the parts produced by high-speed sintering (HSS) and SLS process. They stated that HSS was faster and effective in fabrication of functional components with similar geometrical accuracy of SLS parts. Armillotta et al. performed experimental and analytical studies to investigate the warpage characteristics of FDM-processed acrylonitrile butadiene styrene (ABS) parts through considering the elastic and plastic behaviour of single and multiple layer shrinkage. They observed that the shrinkage and surface roughness increased rapidly due to transient thermal distortion imposed by higher layer thickness.

Singh et al. developed an RSM-based central composite design to optimize the process parameters of SLS process. They reported that the scan spacing and the laser power were the most influencing parameters which affected the shrinkage of SLS parts. They also stated that the increase in scan spacing and laser power had a positive and negative impact, respectively, on shrinkage. Shi et al. considered the influence of polymer properties, including particle size, molecular weight, crystallization rate and molten viscosity, on the shrinkage of SLS parts and found that the dimensional accuracy of SLS parts mostly depended on crystallization rate.

One of the major challenges for producing the parts using AM process is to achieve the better surface quality, which is a function of many factors such as process parameters, powder properties, tessellation from the computer-aided 3D model, slicing algorithm and part geometry. Several researchers attempted to enhance the surface quality of AM parts through regulating the consequence of process variables. Yang et al. investigated the surface quality of stereolithography (SLA) parts by coating polyethylene wax film less than 0.1 mm on the fabricated specimen using ultra-high-pressure atomizing technique and found that the surface quality improved considerably. Launhardt et al. compared the tactile (profile measurement) and optical methods (focus variation, fringe projection and confocal laser) for examining the surface roughness of SLS parts. They found that the tactile method is superior with respect to faster and better evaluation than the optical methods.

Mahapatra and Sood identified raster width, thickness of each layer and part orientation are the most influencing variables on surface quality of FDM parts. Sachdeva et al. explored the consequence of process variables on surface quality of SLS parts using RSM and found that inputs of laser and scan spacing were critical variables in affecting the surface finish. Negi et al. investigated the influence of process variables on surface quality of polyamide parts produced through SLS process using statistical approach. They proposed that the increase in heat energy and scan length led to the enhancement of surface quality, whereas the increase in scanning speed and scan spacing reduced the quality of parts. Vahabli and Rahmati described an analytical model to envisage the surface roughness of ABS parts produced by FDM process. Sachdeva et al. considered RSM to optimize the SLS parameters on surface quality of sintered parts. Sood et al.developed a hybrid approach of weighted principal component analysis and bacteria foraging optimization algorithm to optimize the process parameters on surface roughness of FDM built parts.

In recent times, numerous multi-criteria decision-making (MCDM) approaches including grey relational analysis (GRA), analytical hierarchy process, VIKOR and technique for order preference by similarity ideal solution (TOPSIS) are successfully exploited to solve the non-linear multi-response problems. Among these techniques, GRA approach is found to be an appropriate decision-making methodology for assortment of the optimal variables in advanced manufacturing processes due to its simple computational procedure, ability to reduce the intricacy in decision-making and minimize the computational burden.

Sood et al. effectively utilized the GRA technique for the investigation of dimensional accuracy of FDM-ABS specimens. They have proposed that the combined approach of Taguchi and grey can be effectively used for modelling and optimizing the FDM process parameters. Sood et al. investigated the influence of FDM process parameters on shrinkage characteristics of fabricated plastic parts using GRA technique. They found that the GRA approach can be easily adopted for modelling and parametric investigation of AM processes.

In SIS, several factors including sintering (heater energy, heater feedrate and part bed temperature), printing (inhibitor type, printer feedrate and printer frequency) and material characteristics (composition, particle size) influence the part quality. Hence, it is essential to conduct a detailed study of SIS parameters and their influence on part quality. It helps in determining optimum parameters for both the process and the product. Few studies have brought out the influence of SIS process variables on sintered part quality and performance characteristics. Asiabanpour et al.examined the influence of process parameters on dimensional accuracy and surface quality characteristics of sintered parts using desirability approach. They have identified that heat energy, printer feedrate and layer thickness are more influencing the quality of SIS sintered parts. Authors' earlier studies dealt on numerical and experimental studies of sintering process and also influence of selected SIS process parameters. Aravind et al. and Arunkumar et al. performed the finite element analysis of single and multi-layer thermo-structural sintering interaction for diverse polymer materials. Rajamani and Balasubramanian fabricated the high-density polyethylene (HDPE) parts using SIS system and evaluated the mechanical strength of sintered parts using response surface approach. Their results revealed that the mechanical strength of specimens is improved by increasing the heater energy and reducing the thickness of powder layer. Balasubramanian et al. studied the wear properties of HDPE parts produced by SIS process through varying the SIS process variables. They have proposed that the applied heat energy and layer thickness predominantly influence the wear resistance of sintered parts. Rajamani et al studied the shrinkage characteristics of SIS-processed HDPE parts using RSM and desirability approach. They have found that the shrinkage of sintered specimens is significantly influenced by heater energy and layer thickness.

It is thus evident from the literature that the quality and performance of AM parts can be improved through appropriate selection of process parameters. It is also observed that the influence of process variables on the surface quality of SIS-processed HDPE parts is not well developed yet. Hence, this study analyses the significance of SIS process variables such as heater energy, layer thickness, heater and printer feedrate on surface roughness characteristics of SIS-processed HDPE parts. Subsequently, optimization of these parameters is performed to improve surface quality. The SIS experiments are designed and conducted based on Box–Behnken design (BBD) of RSM technique. Empirical models are constructed to determine the influence and interaction of the selected parameters on roughness characteristics. Optimal processing condition for SIS process is obtained through RSM coupled with GRA.

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