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Aims and Scope

Journal of Mechanics and Structure is a journal which offers prompt publication of structural design; this journal publishes peer-reviewed technical papers on state-of-the-art topics and future developments of the profession. Engineers, consultants, and professors detail the physical properties of engineering materials (such as steel, concrete, and wood), develop methods of analysis, and examine the relative merits of various types of structures and methods of fabrication. Subjects include the design, erection, and safety of structures ranging from bridge to transmission towers and tall buildings; technical information on outstanding, innovative, and unique projects; and the impact of natural disasters and recommendations for damage mitigation.

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Contents

Competence to Energy Consequence with Self-Power-Driven Sensor for Assessing Air Parameters

[1]G. Ramachandran, [2]T. Muthu Manickam, [3]N. Manikanda Devarajan,[4] S. kannan [5] V. Manikandan, [6] S. Deepika

[1-6] Assistant Professor, Dept of Electronics& communication Engineering

[1,-5] V.M.K.V Engineering College, Salem Tamil Nadu, India

[6]NPR College of Engineering &technology

A B S T R A C T

Assessing air parameters are important in many applications. This project monitors the air parameters like temperature, velocity and humidity with the help of electromechanical generator scavenging energy f rom t he airflow. It periodically transmits the measured air parameters to a receiving unit.

The system basically consists of two macro blocks, respectively: solar cell along with the self- power wireless sensor and the receiving unit. The self-powered sensor has a section devoted to the energy harvesting, exploiting the movement of an airscrew shaft keyed to a dc motor when the airflow is greater than 4m/s. The solar cell helps to power the transmitter continuously even when the airflow is less than 4m/s. The data transmission is with radio-frequency transmitter at 433 MHz, allowing covering a distance between the sensor and the reader on the order of 4–5 m, depending on the power supplied in transmission.

The air velocity is measured through the rotor frequency of the electromechanical generator whereas, for the temperature, a commercial thermistor is used, and for humidity, a low power sensor is used. The system can be used for real-time monitoring of air parameters. The sensor module placed into the duct does not require any batteries which reduces size, weight and unwanted maintenance burden of replacement.

Keywords: Temperature Transmitter, Receiver, Sensor, Velocity.

1. INTRODUCTION

1.1. An Outlook

Airflow measurements contribute to determine the indoor air quality and to provide healthy environments for the occupants of the buildings. The commercial airflow measurement system commonly requires a battery, but, recently, in the literature, alternative systems supplied by power-harvesting modules are proposed. However, there are many reasons to eliminate the battery adoption: the size and weight of the devices and the unwanted maintenance burdens of replacement. Moreover, the disposal of the increasing number of batteries is creating an important environmental impact as they contain toxic chemicals.

This project describes a self-powered sensor that, without any battery, autonomously performs the measuring functions and transmits data to an external receiving unit. The proposed sensor is powered by a harvesting system that exploits the mechanical energy coming from the velocity of airflow. Since particular power supply is not required, the self-powered sensor can easily be installed at any point of a building. In the literature, airflow harvesters are evaluated for their potential utilization in autonomous measurements.

1.2 Objective

This project monitors the air parameters like temperature, velocity, and humidity using electromechanical generator scavenging energy from t h e airflow has been designed and tested. It periodically transmits the measured air parameters to a receiving unit. The system basically consists of two macro blocks, respectively: solar cell along with the self-power wireless sensor and the receiving unit.

In general, it is necessary for the power consumption of the harvesting electronics to be less than the available power for harvest, which varies as a function of airflow velocity. In recent years, several groups have demonstrated small airflow harvesters based on the wind turbine principle. For this purpose, a properly sized small airflow turbine is required to exploit the available airflow potential for producing electrical energy. An airflow measurement system for velocity higher and lower than 5 m/s with power- harvesting capability is proposed for short- range application for monitoring purposes.

The self-powered wireless sensor does not require any battery since it uses the power harvested from the mechanical energy of the air flow. The sensor sends the measured data to an external receiving unit. The sensor continuously operates for airflow greater than 4 m/s. For slower flows, the sensor is off, and the data is transmitted with the help of solar power. The measurement data are acquired every 2 s. The receiving unit is always on and ready. The system allows real-time measurement.

1.3 Self-Power-Driven Sensor

In self-powered wireless sensor a commercial airscrew is connected to an electromagnetic generator. The harvested power, using the air motion energy, supplies an electronic circuit for the measurements of air temperature and velocity. The microcontroller, which coordinates the operation of the self-powered wireless sensor, initially is in an idle state. Every 2 s, it wakes up and switches on the sensor modules to execute temperature and velocity measurements.

Subsequently, the microcontroller turns on the transmitter module and sends the package; after the transmission, it returns to the idle state. On the other hand, when the transmission power consumption is high, the energy storage system is recharged during the interval in which the sensor module is off. The interval of 2 s was considered sufficient to allow proper operation of the system since the measured quantities (temperature, humidity and velocity) have a slow dynamic. Finally, the microcontroller switches off the transmitter and returns to the idle state. Since the self-powered sensor is a wireless device, it encounters the typical problems of a wireless network.

In this application, a point-to-point communication has been implemented. Point-to-point communication avoids managing the complexity of a network protocol, saving power, and making the system compatible with the available low energy. For these reasons, the self-powered sensor implements a simple communication at 433 MHz; other wireless protocols such as Bluetooth or Wi-Fi are more expensive in terms of power consumption.

1.3.1 Airflow Power

The number of blades of an airscrew is related to the efficiency at low velocity; geometry with a low number of blades ensures a higher efficiency at low velocity. The available theoretical airflow power can be calculated with the kinetic energy, according to the following expression:

$$E = \frac{1}{2}mv^2 = \frac{1}{2}\rho A\Delta t v^3 \qquad (1)$$

Where ρ is the fluid density, A is the area normal to flux, v is the airflow velocity, Δt is theobservation time, and m is the mass. The kinetic energy can be easily converted into the airflow power

$$P_W = \frac{1}{2}\rho A v^3 \qquad (2)$$

This power is a function of area A, airflow velocity v, and air density ρ, which can be assumed to be of 1.2 kg/m3 in civil and industrial contests. However, the theoretical maximum quantity of energy for a standard area of 55 cm2 and an air velocity of 4.5 m/s is about 300 mW. A generator module cannot extract all of this power since the relatively high viscous drag on the blades, the bearing losses, and other factors. The formula is corrected with a power coefficient that is less than unity Cp. Large-scale airflow harvesters can be highly efficient, with power coefficients greater than 0.5; for small-scale airflow harvesters, the performance is less good, i.e., about 0.1. This large variation in efficiency is caused by friction in the generator, internal electric resistance, and other nonidealities in the transduction between mechanical and electrical energy. The power extracted by a practical turbine is thus

$$P_m = \frac{1}{2}C_p \rho A v^3 = C_p P_W \qquad (3)$$

Assuming that the turbine is coupled to an energy transmission with efficiency ηm that drives a generator of efficiency ηg, the electrical power Pe available can be written as

$$P_e = \eta_m \eta_g C_p P_w \qquad (4)$$

The energy harvester efficiency is defined as the power extracted from the airflow over the kinetic power available for the area covered by the airscrew.

1.3.2 Sensor Activities

The entire device has a low-power configuration: all the unused peripherals are switched off. To maintain the power consumption low, the clock of the microcontroller is 4 MHz during measurement and transmission activities, whereas the clock is 31 kHz during stop mode.

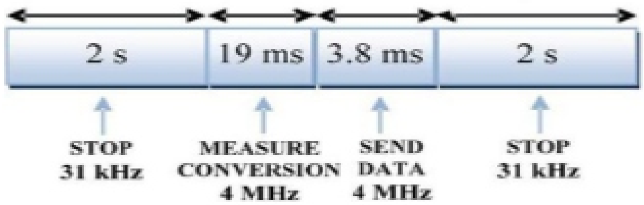

Fig. 1.1 Sensor Activities

In Fig. 1.1, the time interval of each activity is given; the stop mode is 2 s long: in this state, the microprocessor clock is set to 31 kHz. Subsequently, the system wakes up and measures the temperature, humidity and velocity in about 19 ms, sends these data to the receiving unit in 3.8 ms, and then switches off. The transmission packet consists of 60 bits: two nibble for the start and end transmission synchronization and three measurement data, each of 16 bits.

1.3.3. Wake-Up Signals Of Sensor

The unregulated voltage of the generator, the regulated voltage of the self-powered wireless sensor, the main system clock, and the data sent to the transmitter are reported in Fig. 1.2

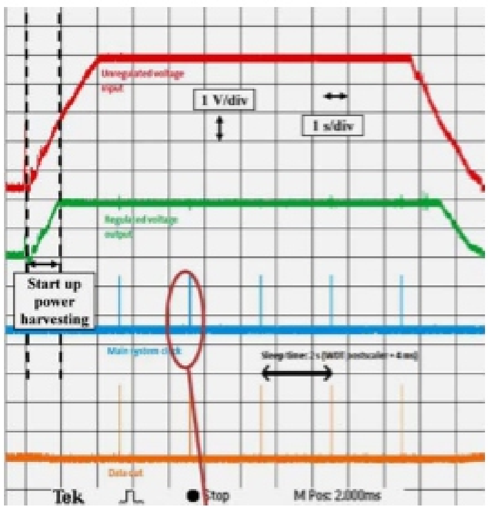

Fig. 1.2 Wake-up Signals

In the time interval labeled as "Start-up power harvesting," the airflow generator is turned on, and the power-harvesting module begins to power the sensor. The start-up time is about 1 s. From this moment, the system is powered, and it continuously works, as long as the airflow velocity is maintained.

2. SYSTEM ANALYSIS

2.1 Existing System

The self-powered sensor that, without any battery, autonomously performs the measuring functions. The sensor is powered by a harvesting system. It exploits the mechanical energy coming from the velocity higher than 4m/s of airflow for short range applications.

For slower flows, the sensor is off, and the receiver assumes that the velocity of air is below the threshold. It measures only the air temperature and velocity. The parameters cannot monitored whenever the wind speed is < 5m/s. This speed of airflow will not be sufficient to harvest energy and to power the electronic circuit. Real-time monitoring is not possible when the wind speed is low.

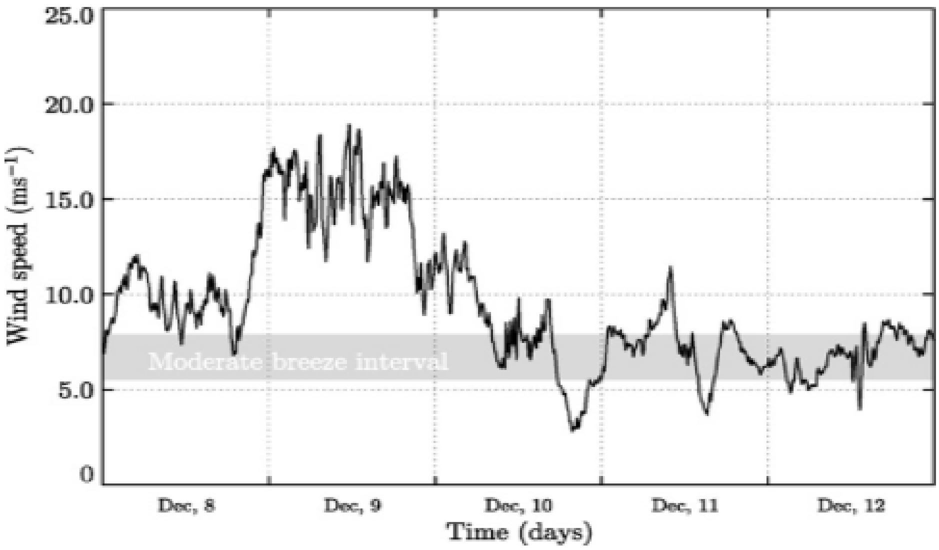

Fig 2.1 wind speed measurements (From reference [6])

From Fig 2.1 the wind speed was above 5m/s for more than 90% of the period, a value that justifies kinetic energy harvesting by a small wind turbine.

2.1.1 Drawbacks

1. The parameters cannot monitor whenever the wind speed is < 5m/s.
2. This speed of airflow will not be sufficient to harvest energy and to power the electronic circuit.
3. Real-time monitoring is not possible when the wind speed is low.

4. The number of blades of an airscrew is related to the efficiency at low velocity.

5. This system only measures two air parameter i.e., temperature and velocity.

6. The receiver not receives any data when the sensor is off in the transmitter.

2.2 Proposed System

The self power-driven sensor is powered by a harvesting system. It exploits the mechanical energy coming from the velocity higher than 5m/s of airflow for short range applications. A self-powered sensor is powered by the servomotor to harvest energy from the airflow when it is > 5m/s.

The solar cell helps to power the transmitter continuously even when the airflow is less than 5m/s. It periodically transmits the measured data to a receiving unit. Airflow harvester can power the self-powered wireless sensor permitting air parameter measurements. An airflow measurement system for velocity higher and lower than 5m/s with power- harvesting capability is proposed.

The sensor continuously operates for airflow greater than 5 m/s. For slower flows, the sensor is off, and the data is transmitted with the help of solar power. The measurement data are acquired every 2 s. The receiving unit is always on and ready. The real time monitoring of air parameters is possible forany wind speed. Proposed system not only measures the parameter like temperature and velocity but also it measures humidity range in air.

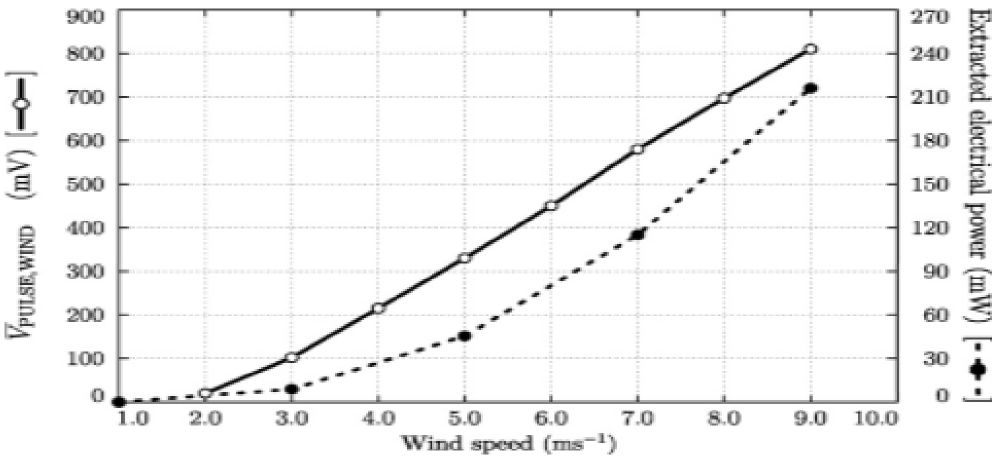

Fig 2.2 Wind speed Vs Power (From reference [6])

Fig 2.2 shows the wind speed verses voltage and power. Wind speed sensor transfer function (solid line) and extracted electrical power (dashed line) obtained from the prototype of small wind turbine evaluated.

2.2.1 Advantages

1. The solar cell helps to power the transmitter continuously even when the airflow is less than 5m/s.
2. The real time monitoring of air parameters is possible for any wind speed.
3. Proposed system not only measures the parameter like temperature and velocity but also it measures humidity range in air.
4. Point-to-point communication avoids managing the complexity of a network protocol, saving power, and making the system compatible with the available low energy.

3. PROJECT DESCRIPTION

3.1 Problem Definition

The intent is to use the device indoors, in air ducts used for heating, ventilating, and air conditioning, the airflow, which is normally present, is used to drive a miniature electro- magnetic airflow harvester to harvest the energy for the power supply. The harvested power, using the air motion energy, supplies an electronic circuit for the measurements of air temperature, humidity and velocity.

The air velocity is measured through the rotor frequency of the electromechanical generator, whereas, for the temperature and humidity, a commercial low-power sensor is used. The sensor is powered by a harvesting system. It exploits the mechanical energy coming from the velocity higher than 4m/s of airflow for short range applications. For slower flows, the sensor is off, and the receiver assumes that the velocity of air is below the threshold. It measures only the air temperature and velocity. The parameters cannot monitor whenever the wind speed is < 5m/s. The parameters cannot be monitored when the wind speed is low; therefore the real time monitoring is not possible.

To overcome the above condition, one more renewable source is used other than the wind i.e., solar energy. With the help of solar energy the electronic circuit in the transmitter is powered to monitor the data whenever the wind speed is less than the threshold level.

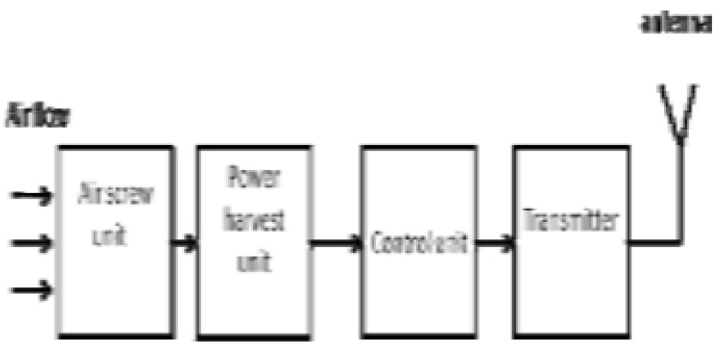

Fig. 3.2.1 Simple block diagram of Transmitter

3.2 Transmitter Module

The efficiency of the air screw unit depends upon the number of blades. The air screw unit harvest power according to the wind flow. The power harvest unit gets the power either through the air screw unit or through the solar cell. The control unit and the transmitter are powered via the harvesting unit. No battery is used. It transmits the measured data to the receiving unit from the harvested power.

3.3 Receiver Module

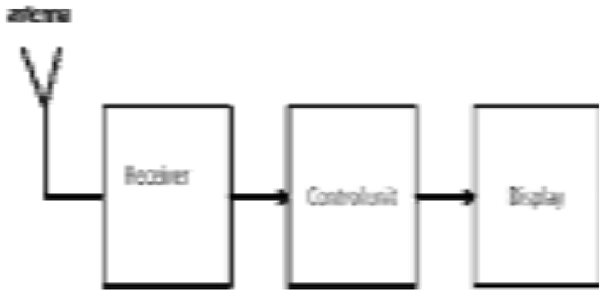

Fig. 3.3.1 Simple block diagram of Receiver

The receiver module is always ready and on to receive the measured data. The data here is air temperature, humidity range in air and air velocity. The receiver is placed is 4-5m apart from the transmitter. It just displays the measured data from the remote location. This system helps to monitor the weather of a remote area. The received data is either displayed in LCD or in PC for further comparison with the standard levels or can also be used to perform a controlling action or to control the next stage in industrial application.

3.4 BLOCK DIAGRAM:

3.4.1 Transmitter

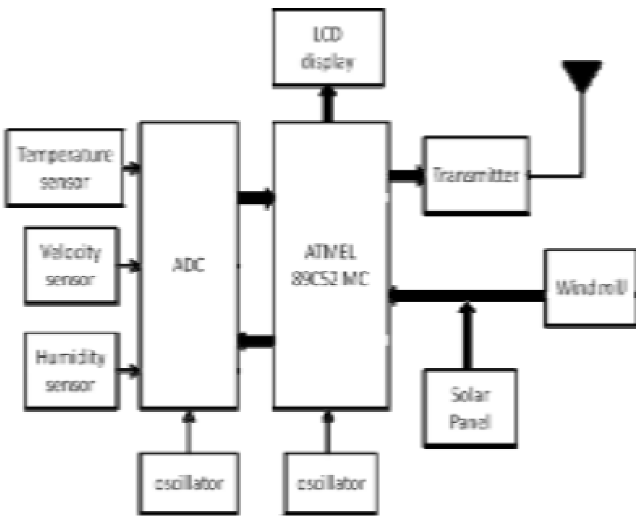

Fig. 3.4.1 Block diagram of Transmitter

3.4.2 Receiver

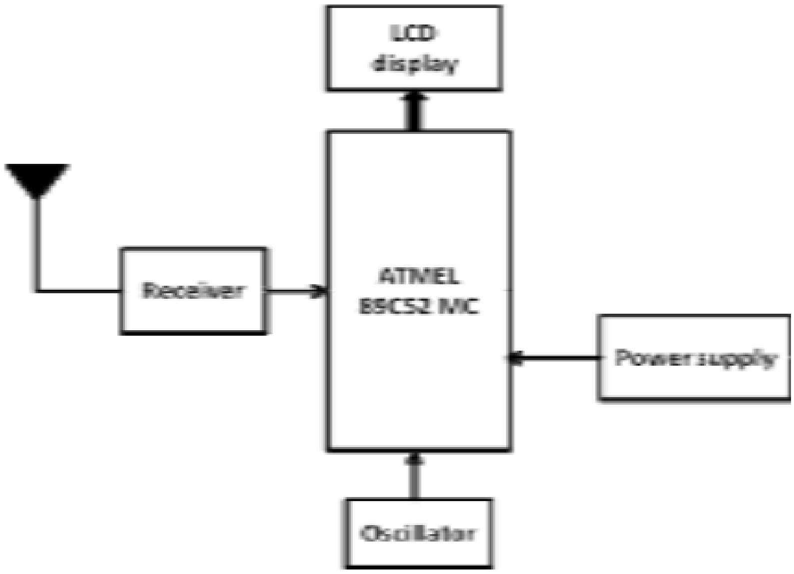

Fig. 3.4.2 Block diagram of Receiver

3.4.3 Transmitter

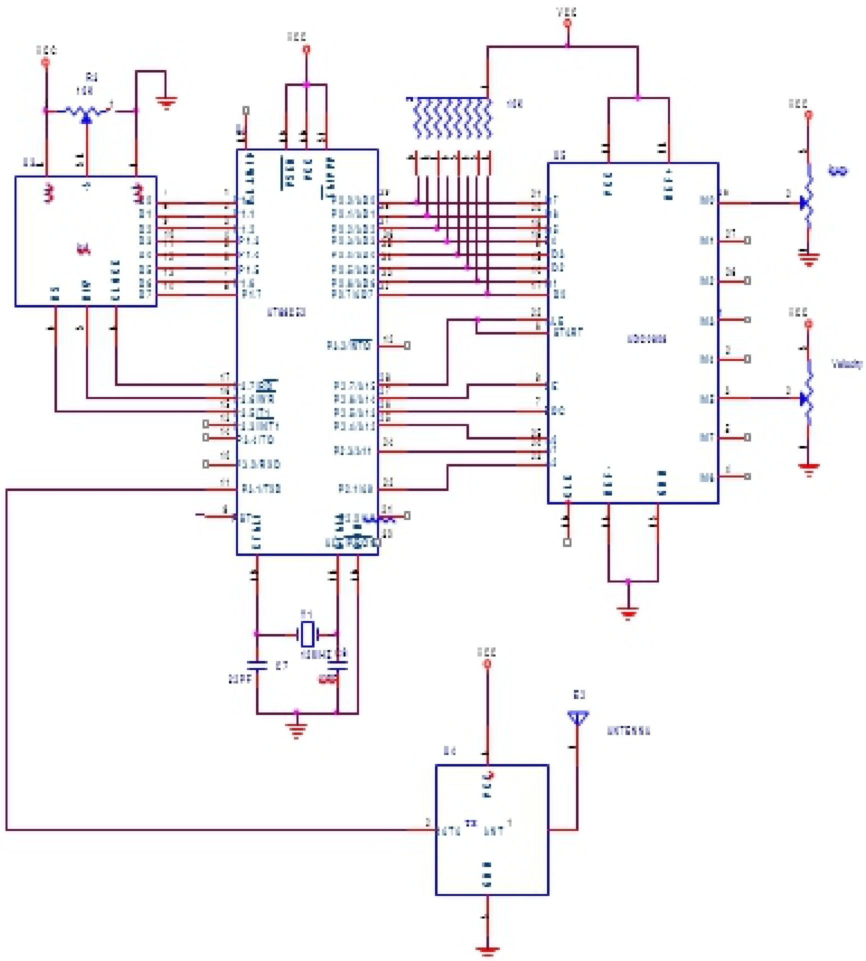

Fig. 3.4.3.1Circuit diagram of Transmitter

3.4.4 RECEIVER

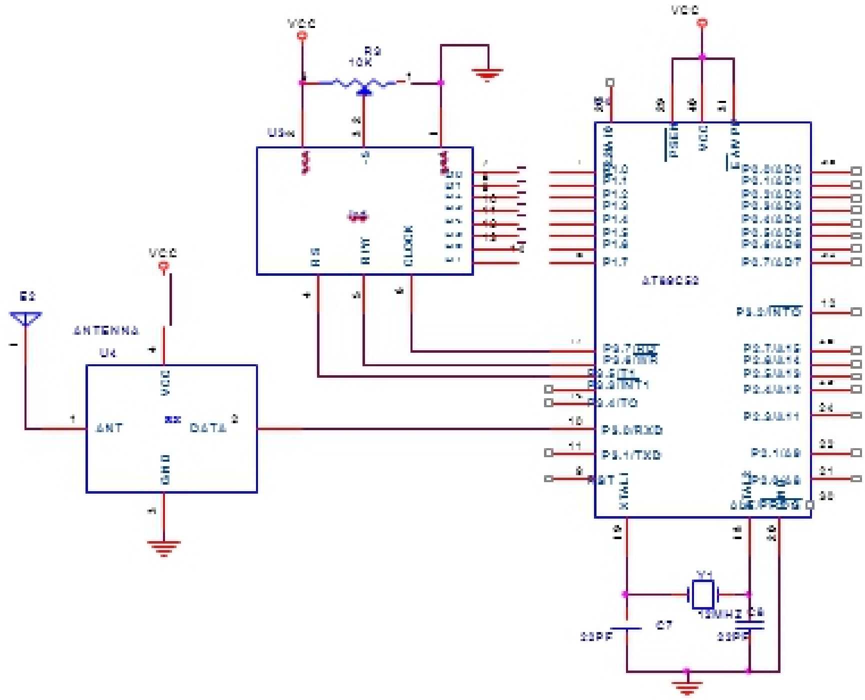

Fig. 3.4.4.1 Circuit diagram of Receiver

4. CIRCUIT DESCRIPTIONS

The complete circuit diagram (Fig 4.10-TX Module & Fig 4.11-RX Module) of the remote monitoring of power parameters is shown in the figure. The power supply is provided in the circuit, the capacitor connected to Pin No.9 (RST) provides the power on reset of the micro controller.

4.1 Potential Transformer

It is energized by the input. Theoretically the potential transformer convert in its input of 250V which as 12V. The output of the potential transformer is led to the potential divider to reduce the voltage further. To move further the output of the potential divider has to be given to a rectifier for producing direct voltage. But specifically we have to use full wave precision rectifier.

4.2 Current Transformer

This transformer used with low range ammeter to measure currents in high voltage in alternating current circuits. The current transformer is used to reduce the current of a substation to a considerable range. It has a primary coil of one term of thick connected in series with the line whose current is to be measured. A secondary consists of a large number of terms of line wire and is connected across ammeter terminal. As regarding the transformer is step up variety but it obvious that current will be step down. The current transformer has primary to secondary current ratio of 100:5. Then it will up the voltage twenty timing whereas it steps down the current to 1/20 of its actual value. Hence if we know current ratio 1/12 of the transformer and the reading of the AC ammeter, the line current can be calculated. In fact the current transformer gives the current at sense ratio times on the ammeter. Since the ammeter resistance is very low.

4.3. Clock and Reset circuit

The clock and reset circuit is functioning both the transmitter side and receiver side. Two no. of 22 pf capacitors, are connected to pin 18 and 19 of the micro controller respectively, with a 12 MHz Piezo electric crystal across them. The clock frequency of the micro controller is depends upon the frequency of the crystal, oscillator used. Typically maximum and minimum are 1 MHz and 16 MHz respectively. So we should use the Piezo electric with this frequency range.

The circuit has two parts

1) Transmission end
2) Receiving end.

4.4 Transmitter

The complete circuit diagram of the transmitter part is shown in the figure. If the power supply is provided in the circuit, the capacitor connected to Pin No.9 (RST) provides the power on reset of the micro controller. LCD directly connected to micro controller port 1. Control lines are connected to port 3. ADC line directly connected to port 0. ADC addresses and control lines are directly connected to port 2. Transmitter lines are connected to port 3.

4.5 Receiver

The complete circuit diagram of the receiver part is shown in the figure. If the power supply is provided in the circuit, the capacitor connected to Pin No.9 (RST) provides the power on reset of the micro controller. Micro controller directly connected to LCD, 8 bit port – 0 serial data transmission. Transmitter and receiver are connected to TX/RX port in micro controller (port 3).

5. OUTPUT

The power required by the self-powered wireless sensor in the activities is reported in Table 7.1. As can be seen from the table, the power consumption during measurement activity and stop mode is low, whereas the RF transmission requests about 28 mW of power supply, with a current consumption of about 13 mA and a voltage level of about 2.2 V. The time interval for transmission is still very short, the energy required is greater than the instantaneous power produced by the harvester, and it is extracted from that stored into the capacitors. Furthermore, since the voltage level generated by the motor is variable and no more than 2.2 V is required by the electronic circuit, the choice of using low power linear regulator is the simplest.

5.1 Table 7.1 Power Consumption

	Current consumption	Voltage level	Power supply
Measurement activity	280 µA	2.2 V	616 µW
RF transmission	13 mA	2.2 V	28 mW
Stop Mode	40 µA	2.2 V	88 µW
Temperature sensor	7.5 µA	2.2 V	16.5 µW
Velocity sensor & conditioning	100 µA	2.2 V	220 µW

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Investgation on IC Engine Combustion with the Concept of HCCI Technology

P. V. Ramana*

* Associate Professor – Mechanical Department, CVR college of Engineering –Hyderabad T.S) – India. (Research Scholar JNTUA-A.P)

ABSTRACT

Many researchers have started by taking initiation to find the suitability for the reduction of fossil fuel combustion by the way of usage of bio fuels like bio-diesel to control the environment pollution but due to less calorific value of bio-fuels engine performance is not up to the expectation and started researches toward reduction of emission by technology changes, such as exhaust gas recirculation, engine modifications and catalytic after treatment.

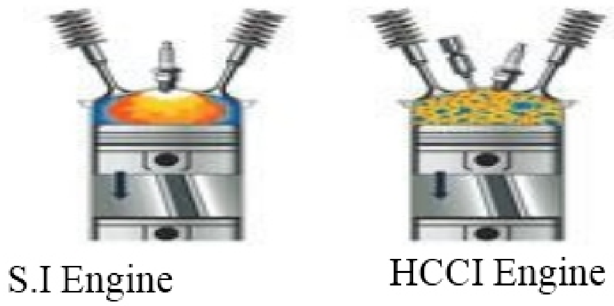
Another way of alternative is by using non conventional source of energies like solar and wind power to reduce the usage of fossil fuels and to increase the availability in nature. At present in this direction also lot of researches are going on to bring down the unit cost production but it is unaffordable for the common man. For the use of common man because of high cost of unit production the other direction of research is started to improve the existing engine combustion technology because it is quite old principles have not changed from since long, with suitable modification in the design and combustion pattern. In this aspect it come researchers mind to change the heterogeneous combustion of CI engine by the way of introducing homogeneous combustion.Toburn the lean mixture in diesel engines homogeneous charge combustion is very efficient way to burn the lean mixture because of Homogeneous Charge Compress Ignition (HCCI) combustion system combines the SI engine and CI engine combustion advantages by using the concept of homogeneous charge combustion. Homogeneous Charge Compression Ignition (HCCI) is with least environmental pollution, because of least emissions from SI engine and more fuel efficiency from CI engine. Homogenous Charge Compressed Ignition. Improvement in fuel efficiency, combustion stability was observed when HCCI applied to two stroke engines and also observed the fuel efficiency of 50 % was improved in case of four store as compared to the SI engine .so this paper is focused on history and development of combustion technology of IC engines with its changes in combustion pattern.

Keywords—IC engine, HCCI, CI Engine,SI Engine,Twostroke Engine, Four stroke Engine,VCR,VVT

I. INTRODUCTION

If we go in to internal combustion engines like petrol and diesel engines the basic principle of combustion not changed from since long. Otto cycle for petrol engines based on constant volume heat addition and rejection developed by N.A Otto Germany scientist in the year 1876 combustion is initiated by spark plug and Diesel cycle developed by German Engineer Rudolf Diesel in 1892 with the concept of compression ignition. These two cycles are successful for practical implementation even though it has less efficiency when compared with Carnot cycle. Carnot cycle is not a practical cycle but it will have high efficiency compared with the other cycles which was developed by Sadi Carnot, a French engineer in the year 1824 later on to get the same efficiency of Carnot tried with other cycles like Stirling and Ericsson cycles but these are not successes in practical application. So Otto (SI) and diesel (CI) cycles are come in to use. SI engine combustion with the concept of homogeneous mixture, heterogeneous combustion, problem of detonation in end gas combustion, less thermal efficiency, throttling losses but in case of Two stroke engine unstable, irregular, incomplete part load combustion which is responsible excessive emissions of unburned hydrocarbons. CI engine combustion with the concept of heterogeneous mixture, heterogeneous combustion and with high NOx and particulates .In practical implementation SI and CI engines are having very less problems and convenient to use so focus is not given much for further modification by the researchers till the end of 1960s.significant research work was performed from the year 1960 to the end of 1970, Many studies were performed during this period by jo et al. to investigate the part load lean combustion of two stroke engine.

Present trend of increased fuel consumption, due to increased population, urbanization and transportation like electrical trains, automobiles. So consumption of fossile fuels increased yearto year and fuel reserves are depleting in a faster rate. Most of the power getting from the thermal power station around 60% and hydraulic power is around 25% balance is from other sources like nuclear ,wind and solar power. it was observed the fuel consumption is increased by more than 10%in every year from last 7 years and giving more emissions, environmental pollution like HC,CO, NOx, soot and leading to global warming and acid rains. So this is the stage to control the emissions, global warming by implementing the advanced techniques to reduce the consumption. One of the advanced techniques is HCCI combustion concept. It is a form of internal combustion in which the Homogeneous Charge is compressed to the point of auto ignition. HCCI not completely the concept of SI engine and not completely the concept of CI engine but it incorporates the best features of both spark ignition (SI) and compression ignition (CI)concepts . HCCI as an SI engine, it mixes the charge well, which minimizes particulate emissions and as a CI engine, the charge is compression ignited, which leads to high efficiency because of no throttling losses.



Left side figure shows combustion using the spark to ignite air fuel mixture. Right side figure shows the concept of HCCI which uses piston compression for a more complete ignition.

2. INVESTIGATIONS ON HCCI DEVELOPMENT

Many were involved in the development of the concept of combustion in different stages those are given below from the collected data of previous publications through literature survey.

- ATAC (Active Thermo-Atmosphere Combustion). Onishi et al.(1973) in two stroke engines
- Paul M.Najt and David E.Foster (1983) in four stroke engines – They used Iso-octane and Heptane as the fuel.
- R.H Thring (1989) HCCI in four stroke engine using gasoline and diesel fuels- suggested hybrid HCCI-SI engine
- Thomas ,Ryan et al. (1996) HCCI in four stroke engine using diesel for a wide range of Compression Ratio from 7.5:1 to 17:1
- Aoyama et al. (1996) compared HCCI with DDI and GDI (gasoline direct Injection)– same setup and investigated the effect of supercharging
- Christensen et al.(from 1998)super charging in HCCI with three different fuels (iso octane,ethanol and NG)
- Controlled auto ignition(CAI)combustion with fully variable valve train –Don law et al. and stated that the amount of internal EGR determines the combustion initiation point(Active valve Train was used)
- Jian Li et al. developed a multi cylinder CAI(controlled autoignition) gasoline engine and concluded that 5 to more than 30% reduction in fuel consumption and 90 to 99% reduction in NOX emissions. CO emissions are slightly lower than S.I engine HC emissions are 1.5 to 2.6 times of those from S.I combustion
- CAI combustion of gasoline and alcohol fuels was investigated by Aaron Oakley et al. and concluded that the combustion of alcohols leads to higher engine thermal efficiencies when compared to gasoline and suggested HCCI for part load operation
- George et al (2000) HCCI in four stroke S.I Engine with modifies valve timings
- Toru noda et al –Hydrogen fueled HCCI (Multi zone simulation)
- CAI combustion with fully variable valve train –Don law et al. and stated that the amount of internal EGR determines the combustion initiation point(Active valve Train was used)
- Toshiji et al. investigated the effect of A/F ratio and temp distribution in HCCI by modeling and concluded that pressure profiles depends on two factors Onset timing of overall reaction of the cell.

The magnitude of the time lag of ignition timings among cells

- Prediction of pre-ignition reactivity and ignition delayin HCCI Jincai Zheang et al. they used reduced chemical kinetic model and concluded that negative temp. coefficent. Affects the pre-ignition behavior

- Propane HCCI combustion model using sequential fluid mechanic chemical –kinetic model Salvador M et al. and they suggested that low swirl no cervices and hot walls reduces HC and CO emissions to near zero.
- Four stroke camless engine in HCCI mode using gasoline was experimented by Lucien et al. and they stated - CO,NOX and fuel consumptions were reduced at the same time the level of HC emissions are same when compared to S.I Engine operation
- Jian Li et al. developed a multi cylinder CAI(controlled autoignition) gasoline engine and concluded that 5 to more than 30% reduction in fuel consumption and 90 to 99% reduction in NOX emissions.CO emissions are slightly lower than S.I engine HC emissions are 1.5 to 2.6 times of those from S.I combustion
- Modeling of HCCI combustion and emissions using detailed chemistry william et al.they stated that the most of the CO emissions were formed from unburned fuel-air mix. Flowing from the boundary layer and cervice zones in to the high temp. parts of the cylinder during the expansion stroke.
- Satoshi et al experimented Natural Gas in HCCI engine (Using EGR for performance improvement).

They stated that EGR utilization increases the allowable engine load over 20 % without sacrificing the thermal efficiency and lowers Pmax dramatically

Onishi et al. who managed to get a part load stable two-stroke combustion process for lean mixtures in which ignition occurs without spark assistance. Remarkable improvements in stability, fuel efficiency, exhaust emissions, noise, and vibration were reported.

In 1983 Najt and Foster extended the previous work in two stroke engine to four-stroke engines and attempted to gain additional understanding of physics of HCCI combustion . They are the first to apply HCCI combustion concept in a four-stroke gasoline engine and they considered that HCCI is controlled by chemical kinetics, with negligible influence of turbulence and mixing.

Following figure shows first stage of the heat release curve is associated with low temperature kinetic reaction and the time delay between the first and main heat release is attributed to the negative temperature coefficient (NTC) regime, which locates between the two heat release stages (20, 23) in this negative temperature coefficient regime the overall reaction rate decreases though the in-cylinder temperature increases which leads to a lower reactivity of the system.

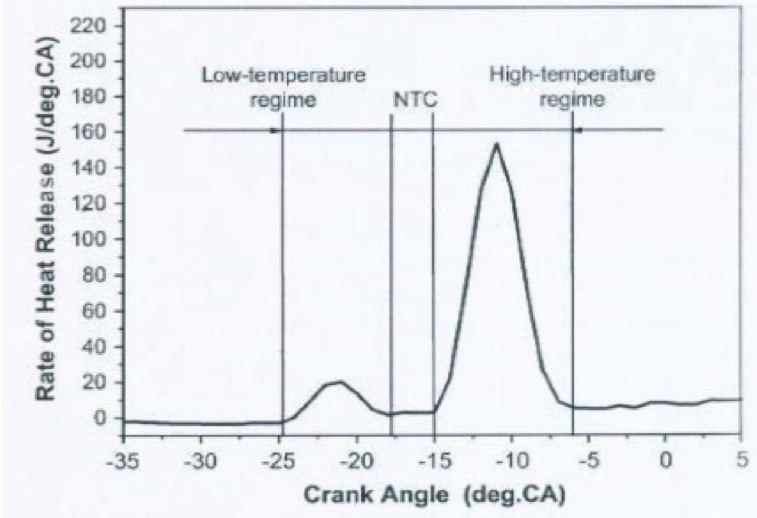


Fig1.n-heptane fuel heat release curve from HCCI combustion

Low temperature kinetics has been studied for some time, as this chemistry is responsible for knock in spark ignition engines heat release from low temperature reaction relates to octane numbers of fuels low octane number is the more obvious the heat release of low temperature reaction for gasoline like fuels (high octane number), heat release from low temperature reaction (first-stage heat release is less compared with diesel like fuel at the same condition. The heat release from low temperature reaction very less to obviously observe from heat release profiles at most conditions for gasoline like fuels. Research with the use of optical diagnostics has shown that HCCI combustion initiates simultaneously at multiple sides within the combustion chamber and there is no discern able flame propagation (14, 16).

3. COMPARISONS OF COMBUSTIONS

HCCI was identifies as distinct combustion phenomenon long ago, HCCI ignition occurs at many points simultaneously with no flame propagation. Combustion was described as very smooth, with very low cyclic variation.

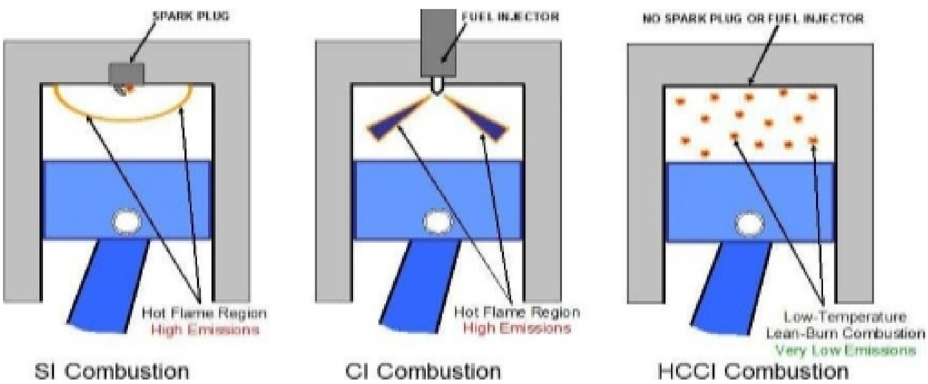


Fig 2: comparison of combustions

Homogeneous charge compression ignition (HCCI), which produces very less NOx, and minimum PM emissions and high thermal efficiency by operating overall lean mixture. HCCI combustion has benefits l ike low NOx emission and high thermal efficiency. However, this combustion mode can produce higher Unburned Hydrocarbons (UHC) and carbon monoxide (CO) emissions than those of conventional engines.

In Spark ignition engines combustion timing is controlled by spark timing and in compressionIg niti on engines is controlled by injection timing but in case of HCCI engine there is no direct method to control the start of combustion timing. Therefore, it is important to control the combustion for best fuel economy and lowest emissions. In controlling the temperature, pressure and composition of the in-cylinder mixture, the following parameters can be considered i n combustion phase of the HCCI engine like fuel characteristics, intake air temperature, air–fuel ratio, fuel injection timing, multiple pulse fuel injections, engine speed. In addition, the engine performance is influenced by the injector spray geometry, exhaust gas recycling (EGR), variable valve timing, swirl ratio, supercharging, compression ratio, and the piston-cylinder.

From HCCI engine principal it is important to realize mixture formation and the avoidance of fuel-wall interactions to achieve high fuel efficiency, reduce HC and PM emissions, and prevent oil dilution. HCCI engine have the potential for high efficiency like diesel, very low particulate emissions Ox and low cost because no high pressure injection system is required but the disadvantages is high HC and CO emissions, high peak pressure, high rate of heat release, reduced operating range, reduced power per displacement and difficulty in starting and controlling the engine. So this paper investigates the past as mentioned above from literature survey and current research done and considerable success in doing detailed modeling of HCCI combustion. Based on research papers it was observed that the implementation of HCCI to gasoline engines is constrained by many factors. The main drawback of HCCI is the absence of direct combustion timing control. Therefore all the right conditions for auto ignition have to be set in HCCI before combustion starts.

From the literature identified the Four main areas of timing control they are one is thermal control through exhaust gas recirculation (EGR) second is variable compression ratio (VCR), third is variable valve timing (VVT), and fourth is fuel injection systems and fuel mixtures(additives). To investigate HCCI Combustion Process a detail CFD (Computational Fluid Dynamics) approach will be used to limit the drawback of HCCI Engine.

3.0 DEVELOPMENT OF HCCI ENGINES

3.1 Two stroke HCCI Engine

The main problems of the two-stroke engines are unstable, irregular, and incomplete part load combustion which is responsible for excessive emissions of unburned hydrocarbons so to overcome the problems Lots of studies were performed from the end of the 1960s to the end of the 1970s by Jo et al. to investigate the part load lean two-stroke combustion. He found that the irregularities of the combustion and the auto ignition were considered as the weak points of the two-stroke engine could be effectively controlled and successfully concluded by the innovative work it was published with his colleague, Onishi et al. who managed to get a part load stable two-stroke combustion process for lean mixtures in which ignition occurs without spark assistance. Remarkable improvements in stability, fuel efficiency, exhaust emissions, noise, and vibration were reported. Onishi and his colleagues named this new combustion process ―ATAC‖ (Active Thermo-Atmosphere Combustion).

Another paper concerning two-stroke auto-ignition was published in 1979 [8]. Noguchi and his colleagues named this auto-ignition combustion the TS (Toyota-Soken) combustion process.

They also concluded that TS combustion occurred similarly without flame front while showing great efficiency and low emissions. They were one of the first to suggest that active radicals in residual gases could play an important role in the auto ignition process.

In the late 1980s, Duret tried to apply Onishi's pioneering work to DI two-stroke engines for improvement of part load emissions. For this purpose, he investigated the idea of using abutterfly exhaust throttling valve as previously shown by Tsuchiya et al. in a carburetted engine. The first application of ATAC auto ignition with direct fuel injection engine was then described in 1990.

CFD calculations showed that by regulating the introduction of intake flow by the use of exhaust control valve [6] the mixing between the residual gas and fresh intake air may be precisely regulated.

Until mid-1990s this research work was further developed and the interest of using transfer port, throttling to even better control the degree of mixing between the fresh charge and the reactive residual hot gas was demonstrated [4].

The first prototype of two stroke direct injection automotive engine using the transfer port throttling technique for better controlling the degree of mixing between fresh and reactive residual gas was presented by Duret and Venturi in 1996. Considering the benefits of combining direct injection with HCCI, this engine was easily able to meet the European emissions standards valid up to the year 2000 with 20% more fuel economy improvement compared to its four strokes without after treatment counterpart of equivalent power output [6].

So In this period ―Ishibashi‖ investigated the possibility of using the auto ignition in two-stroke motorcycle engines. He showed that possible to control the amount of active residual gases in the combustion chamber as well as in cylinder pressure before compression by using a charge control exhaust valve it was. He named this process as ―Activated Radicals (AR) combustion process. AR prototype400 cc Honda EXP-2 was prepared for the Grenada-Dakar rally 1995 and performed very well particular to their high fuel economy compared to the four-stroke motorcycles. This work was further developed up to the first industrial application of AR combustion in production in a Japanese motorcycle model in 1996 and in a European scooter model in 1998 [6].

A new prototype engine named as 2/4 SIGHT which was developed by Ricardo in 2008 which uses HCCI concept. This gasoline engine concept uses novel combustion, boosting, control, andtechnologies of valve actuation to enable automatic and seamless switching between two- and four-stroke operations, An engine equipped with this new system is capable of running on either the 2-stroke or 4-stroke engine cycle, with the aim of delivering significant performance and fuel economy improvements, allowing their V6 test-bed to be downsized from 3.5 liters to 2.0 liters for producing the same power output. This aggressive downsizing leads reduction of fuel about 27% in fuel economy and lowered the emissions significantly.

3.2 FOUR STROKE HCCI ENGINE

In 1983 Najt and Foster extended the previous work on two-stroke engines [8] to four-stroke engines and attempted to gain additional understanding of the underlying physics of HCCI combustion. They are the first to apply HCCI combustion concept in a four-stroke gasoline engine. In this work they considered that HCCI is controlled by chemical kinetics, with negligible influence of turbulence and mixing. By means of heat release analysis and cycle simulation, they conducted experiments using PRF fuels and intake preheating. They pointed out that HCCI combustion process was governed by low temperature (less than 950°K) hydrocarbon oxidation kinetics. Also they concluded as HCCI combustion is a chemical kinetic combustion process controlled by the temperature, pressure, and composition of the in-cylinder charge.

Work of Najt and Foster is further extended by Thring on four-stroke engines in 1989, by examining the performance of an HCCI engine operated with a full-blended gasoline. Theoperating regime of a single-cylinder engine was mapped out as a function of air fuel equivalence ratio, EGR rate, and compression ratio.

Studies have shown that it is possible to achieve high efficiencies and low emissions by using lean mixtures at high compression ratio on four-stroke engines. In case of four-stroke , a quite number of experiments have been performed on combustion of HCCI and studied, with single cylinder engines, which normally do not provide brake thermal values. However, Stockinger demonstrated brake thermal efficiency of 35% on a 4-cylinder 1.6 liter engine with brake Mean Effective Pressure (bmep)at 5 bar. Later studies have shown brake thermal efficiencies above 40% at 6 bar BMEP.

4.0 RECENT ANALYSIS OF HCCI ENGINES

Recent analyses of HCCI engines have used detailed chemical kinetics codes in either single- zone mode or multiple-zone model. It is assume that the combustion chamber is a completely - stirred reactor with uniform temperature, pressure and composition in Single-zone models. Single zone model is applicable to homogeneous charge engines which analyze, predict start of combustion with good accuracy where mixing is not a controlling factor. Beginning conditions of the compression stroke is known, and then can be used to evaluate ranges of operations for different fuels and conditions but a single- zone model is not considering the effect of temperature gradients inside the cylinder. The assumption of uniform charge temperature inside the cylinder results in all the mass igniting at the same time when the ignition temperature is reached. Therefore, a single-zone model under predicts the burn duration, and also over predicts peak cylinder pressure, NOx and is unable to predict the combustion efficiency. HC and CO emissions result from mass in cervices and boundary layers that are too cold to burn to completion. A multi-zone model can take full account of temperature gradients inside the cylinder, and therefore can do a much better job at predicting peak cylinder pressure, NOX and burn duration, and can generate predictions for HC and CO emissions. These benefits are obtained at the cost of a much-increased time for computation compared with a single- zone model. Multidimensional CFD models have the highest potential for predicting realistic results when the geometry of the combustion chamber is resolved in full detail, in combination with a detailed chemistry approach to model combustion. The CHEMKIN chemistry solver is integratedinto the KIVA code for solving the detailed chemistry during multidimensional engine simulations. The KIVA code provides CHEMKIN the species and thermodynamic information o9f the computational cells, and the CHEMKIN code returns the new species information and energy release after solving the chemistry. The chemistry and flow solutions are then coupled.

5.0 REASONS TO GO FOR THE DEVELOPMENT

a. Advantages

- In order to achieve particularly favorable NOx emissions and soot
- The combustion always occurs with excess air, just as with the diesel engine, which also has a positive effect on the specific fuel consumption
- Relative to SI gasoline engines, HCCI engines are more efficient, approaching the efficiency of a CIDI (compression ignition direct injection) engine.

b. Improved Efficiency

- Elimination of throttling losses.
- High compression ratios
- Shorter combustion duration (No Flame front, so distance to travel)
- Fuel-Flexibility

C. Emissions

- HCCI engines also have lower engine-out NOx.
- HCCI engines have substantially lower emissions of PM.
- The low emissions of PM and NOx in HCCI engines are a result of the dilute homogeneous air and fuel mixture. The charge in an HCCI engine may be made dilute by being very lean by EGR.

6.0 CHALLENGES OF HCCI COMBUSTION

The main objective of HCCI combustion is to reduce soot and NOX emissions while maintaining high fuel efficiency at part-load conditions in HCCI engines, the mixture auto-ignites in multiple spots and then is consumed quickly without discernible flame propagation. The mixture is both lean and homogeneous so that little NOx and soot are formed. However, there are still challenges associated with the success fuel operation of HCCI engines. The challenges include the control of the ignition and combustion facing, reduction of high HC and CO emissions and theutilization of EGR, etc. Nonetheless, the fundamental understanding of the combustion process in HCCI engines is still limited, and there has been increasing number of research papers on HCCI. The challenges are as follows.

6.1. The difficulty in combustion phase control

One of the principle challenges of the HCCI combustion is the control of the combustion phasing. Unlike conventional combustion a direct method for controlling the start of combustion is not available. Auto ignition of the fuel-oxidizer mixture is influenced by the properties of the mixture and by the time temperature history to which it is exposed, instead of start of combustion supposed to be established by the auto-ignition chemistry of the air fuel mixture. Hence, combustion phasing of HCCI engines is affected by the factors like auto ignition properties of the fuel, fuel concentration, residual rate and possibility, reactivity of the residual, mixture homogeneity, compression ratio, intake temperature, latent heat of vaporization of the fuel, and engine temperature, heat transfer to the engine and other engine dependent parameters.

6.2. High level of UHC and CO emissions

all homogeneous charge combustion ignitions, during compression stroke a significant portion of the in-cylinder fuel is stored and escapes combustion, and also the burned gas temperature is very low it cannot to consume much of the unburned fuel when it re enters in to the engine cylinder during the expansion stroke which causes increase in noise, unburned hydrocarbons and carbon monoxide emission. This is one more challenge to HCCI engine operation. This results in significant increase in both HC and CO emissions relative to conventional combustion. In addition, the temperature of peak burned gas is are too low (lower than 1400K or 1500K) to complete the conversion of CO in to CO2 by completing the reaction at low loads, and the combustion efficiency deteriorates [19] this loss of combustion at the lightest loads rates the pressure rise so more the engine noise increases significantly if left unchecked it may damage engine [18]

6.3. Operation range

Adding the problems to the above, another fundamental barrier in HCCI development is extending the operating load range whilst maintaining the full HCCI benefi t it is asimportant as the auto ignition process. In addition to expanding the HCCI operation to higher load, very light load operation is also limited, because there is insufficient thermal energy to trigger auto ignition of the mixture late in combustion stroke. More over with low exhaust gas temperature at neat idle operation, excess emissions of CO and HC in combination, makes the combustion mode less appealing from combustion efficiency and exhaust emissions perspectives.

6.4. Cold start

the heat loss from the compressed charge to the cold combustion chamber walls is too high because of operation temperatures are very low at the time of cold start, so the HCCI engine starting will face a major difficulty, so the engine may have to be started in a conventional mode after a short warm-up period then switched to the HCCI mode. Therefore maintaining real homogeneous combustion after the cold sta rt also be a real challenge. Cold starts are an area where much more developmental efforts are required in HCCI operation. Obviously, HCCI benefits in fuel efficiency and emissions is as important as extending the HCCI operations to high loads.

6.5. Homogeneous mixture preparation

For achieving the higher fuel efficiency, effective mixture preparation, avoiding fuel/wall interactions are crucial for achieving high fuel efficiency and also at the same time reducing HC and PM emissions for preventing oil dilution. Fuel impinging on the surfaces of the combustion chamber has been proven disadvantageous to HC emissions even for moderately volatile fuels such as gasoline [20]. Mixture of homogeneity has an effect on auto ignition reactions that control the HCCI combustion phasing [21] and there is significant evidence that low NOx emissions can be produced even with some degree of mixture in homogeneity within the combustion chamber. Homogeneous mixture preparation is most difficult for fuels with reduced volatility such as diesel, which requires elevated intake air temperatures for low smoke operation when port - injected.

7. SOLUTIONS PROPOSED FOR THE CHALLENGES

A. Controlling of HCCI ignition timing

For controlling HCCI combustion timing several strategies have been investigated, and extending the load range with various levels of success. Most of these strategies can be divided into the broad categories of mixture dilution, Modifying fuel properties, fast thermal management and in-cylinder direct fuel injection. Many studies investigating HCCI control

7.1.Mixture dilution for HCCI control

High intake charge temperatures and a significant amount of charge dilution must be present to achieve HCCI combustion. To initiate and sustain the chemical reactions leading to auto ignition processes in cylinder gas temperature must be sufficiently high and to control runaway rates of the heat releasing reactions substantial charge dilution is necessary. These requirements in both cases can be realized by recycling the burnt gases within the cylinder.

One of the HCCI combustion phasing control approach is to advance or retard combustion timing by diluting the cylinder mixture. Najt and Foster showed that HCCI combustion in a four- stroke engine could be controlled by introducing re-circulated exhaust gas into the cylinder intake mixture. Christensen and Johansson showed combustion timing to be slower with higher amounts of EGR.

Within the engine cylinder while processing the presence of the recycled gases have a number of effects on the HCCI combustion and emission. The temperature of the intake charge increases owing to the heating effect of the hot burnt gases when hot burned gases are mixed with cooler inlet mixture of fuel and air. This is often the first case for HCCI combustion with high octane fuels, such as gasoline and alcohols. The second case is, some of the inlet air replaces by introduction or retention of burnt gases in the engine cylinder and hence reduces the oxygen concentration (especially with the EGR). Oxygen present in the air is reduction due to the presence of burnt gases which causes the dilution effect. Third case may be with burnt gases, the total heat capacity of the in-cylinder charge will be higher; it is mainly due to the higher specific heat capacity values of carbon dioxide (CO2) and water vapor (H2O). The rise in the heat capacity of the cylinder charge is responsible for the heat capacity effect of the burnt gases. Finally, combustion products present in the burnt gases can participate in the chemical reactions leading to auto ignition and subsequent combustion.

7.2. EGR strategy of fuel modification

One of the strategies of fuel modification is introduction of EGR and addition of EGR into intake is the most practical means of controlling charge temperature in an HCCI engine. It has been well confirmed that hot EGR enhances combustion in 4 stroke HCCI engines mainly due to the higher temperature of resulting intake mixture, rather than existence of active radicals. In addition to the thermal effects, the inserted gases contained in the EGR can be used to control the heat release rate due to its impact on chemical reaction rates, which can be delay the auto ignition timing, reduce the heat release rate, and thus lower peak cylinder pressure.

There are many other possibilities for HCCI engine control; these include variable compression ratio, variable valve timing, operation with multiple fuels, and thermal control. Out of these options, thermal control is inexpensive to implement and purely based on technologies familiar to manufacturers and may be most acceptable if demonstrated to be satisfactory.

7.3 Fast thermal management for HCCI control

The controlling technique which involves in rapid changing of intake change temperature to control the combustion of HCCI is fast thermal management. Many studies have indicated that HCCI combustion timing is sensitive to intake air temperature. Haraldsson et al. and Yang et al. suggested the use of two air streams and regaining heat from exhaust gases to heat one of the air streams. By mixing two air streams, one direct from atmosphere and the other heated by exhaust gases, it is possible to control the temperature of the final intake air stream (each stream with independent throttles for mixing). Both studies with and without mixing observed the ability of the FTM system to control the combustion phasing of HCCI combustion. One of the studies by Yang indicates that while FTM is effective to control combustion phasing in HCCI engines, the ―thermal inertia‖ of the system makes cycle by cycle temperature adjustment difficult, which in turn complicates the control of HCCI combustion during transients. This lag in achieving the desired HCCI combustion phasing was also observed by Haraldsson research, although in hisstudy.FTM was presented as an acceptable alternative to use variable compression ratio in closed loop control of HCCI combustion.

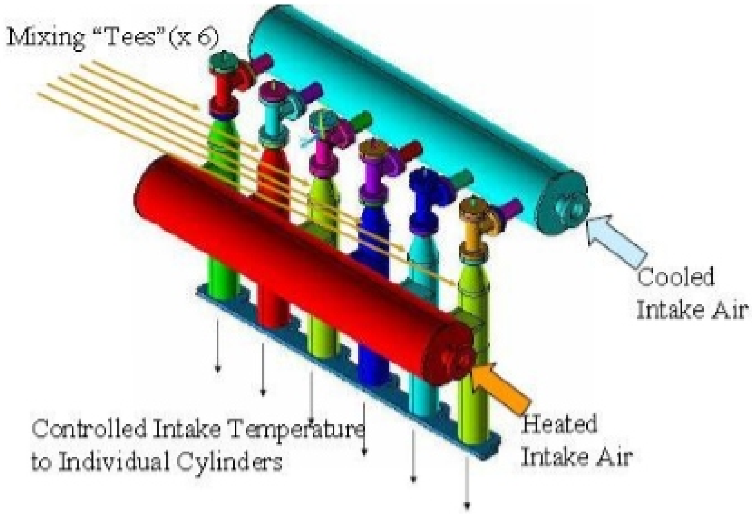


Figure3: fast thermal management

B. Thermal control system:

Thermal control consists of a pre-heater to increase fuel-air mixture temperature and a supercharger to increase mixture density and also an intercooler to decrease mixture temperature. The ultimate resulting system has five independent control parameters which are given under:

- One is equivalence ratio,
- Second is fraction of EGR,
- Third is Intake pressure,
- Fourth is pre-heater effectiveness, and
- Fifth is Intercooler effectiveness.

These parameters can be tuned to meet the load demands while obtaining auto ignition at the desired time and meeting the constraints of maximum pressure and NOx emissions.

Due to the fact that the HCCI mixture is not burned by a discernible flame, the physics of flow-combustion interactions in a typical burning flame are considered to be absent. However, experiments still indicated the local fluctuations recorded by fuel in homogeneity. The features of in homogeneity could become important in the high EGR cases. In fact, it has not been successful to use chemical kinetics alone to simulate the combustion by assuming a uniform temperature distribution, i.e., the single-zone model. The high temperatures in the center of the chamber are responsible for the ignition. To account for the temperature stratification, a multi- zone model was used which divided the entire mixture into several groups. The effects of engine flow field on combustion are still not considered. On the other hand, due to the possible in homogeneity in mixture and temperature distribution, it has been suspected that the turbulence also has effects on the combustion rates. It is still a question whether the mixture is completely homogeneous and the turbulent mixing has no effect on the heat release rates.

7.4. Starting System

HCCI engines are often difficult to start. At cold start, the compressed gas temperature in an HCCI engine is reduced because the charge receives no preheating from the intake manifold and the compressed charge is rapidly cooled by heat transfer to the cold combustion chamber walls. Without some compensating mechanism, the low compressed charge temperatures could prevent an HCCI engine from firing. A common approach has been to start the engine in spark ignition mode or diesel mode and transition to HCCI mode after warm-up. However, success full transition typically required advanced engines equipped with variable compression ratio (VCR) or variable valve timing (VVT), which may be expensive or difficult to implement for heavy duty engines. In practice operation in SI mode requires equivalence ratio of 0.6 -0.65 or greater (Flynn et al. 2000).which is high enough to damage the engine if thermal auto ignition or knock occurs during the transition. Instead of attempting to start the engine in SI mode and transition to HCCI mode, a brand new approach is used to start the engine directly in HCCI mode by preheating the intake with a gas fired burner. This was easy to implement by adding a burner to the pre-heater. The burner is run for a period of time (30 minutes) until the pre-heater reaches a high temperature (300°C).At this condition, running the intake charge through the pre heater while simultaneously spinning the engine with an air starter is enough to achieve HCCI ignition. After ignition, combustion is self sustaining and the burner can be turned off, as the intake gases are heated by the hot exhaust. The burner is a source of emissions and a consumer of fuel, and as such in a practical deployment of an HCCI engine for stationary power generation. This would have to be considered as a contributor to the overall system emissions and fuel consumption.

7.5 Compression ratio

Christensen et al. of his several investigations express the Compression ratio as an effective means to achieve HCCI combustion control. Through his studies demonstrated that regardless of fuel type used increasing the compression ratio from 9.6: 1 to 22.5: 1 had a strong influence on ignition timing and assists in decreasing the necessary intake charge temperature. Hiraya et al. also reported the effect of compression ratio through his studies from 12: 1to 18.6: 1 on setting of Olsson et al. investigated the influence of compression ratio on a natural gas fuelled HCCI engine. In his experimental study the test engine had a secondary piston whose position can be varied to attain variable compression ratio (VCR). In their tests, the compression ratio was modified (21: 1, 20: 1, 17: 1, and 15: 1) according to the operating condition to attain auto ignition of the charge close to TDC. This VCR engine has shown the potential to achieve satisfactory operation in HCCI mode over a wide range of operating conditions by using the optimal compression ratio for a particular operating condition. The study also showed that higher compression ratio gives the maximum pressure rise for early combustion timing and a reverse effect was seen with delayed combustion on-set.

8.0 LIMITATIONS

- Inability to control the combustion initiation
- Problems in controlling the rate of combustion over the whole speed and load range
- Requirements of some external setups to preheat the air
- Depending on the method used to facilitate HCCI combustion, strong cycle-to-cycle variations can occur. This poses a control problem, but is also a threat for the HCCI combustion
- The HCCI engine has relatively high friction losses due to the low power density.
- if misfire occurs, the gas mixture during the next cycle will be too cold for auto-ignition to occur (unless intake air heating is used) and the engine will stop

9.0 PARTIAL HCCI (PHCCI)

- In Partial HCCI mode the engine is cold-started as an SI or CI engine, then switched to HCCI mode for idle and low- to mid-load operation to obtain the benefits of HCCI in this regime. For high-load operation, the engine would again be switched to SI or CI operation.
- The future of HCCI looks promising especially with partial HCCI mode.

Major companies such as General Motors, Mercedes-Benz, Volkswagen and ford have invested on research of HCCI technology. General motors' company released a test vehicle named as Saturn Aura by using PHCCI technology and the test vehicle is on the road and open Vectra with PHCCI technology is on going under the progress for test conditions. Mercedes-benz released Dies-otto with PHCCI Technology and this is also on the road for test conditions and another company like Volks wagen with the name of Touran with CCS (combined combustion spark), GCI(gasoline compression Ignition) technology are under progressing. Ford company also developing the HCCI technology which is under progressing.

10.0 CONCLUSION

By this time market should have been introduced by many HCCI engines for practical use because of several challenges as mentioned above in the combustion, the engines have not up to the level of matching in cost to release in the market and still it is in undergoing research stage only.

The technical challenges facing HCCI combustion both in gasoline and diesel HCCI, owing to the lack of direct control over the start of ignition and the rate of heat release, their operational range is limited and less optimized combustion phasing. HCCI combustion technology and its future research and application should be considered as part of an effort to achieve a step change in combustion in lowering temperature of combustion for wide range of operating conditions. The future Combustion process of IC engines converges towards combustion of premixed compression ignition, while direct injection and turbo charging will become a norm on such engines. Therefore it may be our futuristic with more flexible engine with realistic possibility with their real-time control and to come in to the practical use as fully flexible engine to convert the chemical energy from any type of fuel into mechanical work through premixed auto-ignited low-temperature combustion [6].

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Improving Power System Stability in Micro-Grid System using Particle Swarm Optimization (PSO) Technique

Mgbachi C.A.C. (Ph.D)
Department of Electrical/Electronic Engineering
Enugu State University of Science and Technology, ESUT Enugu, Nigeria

ABSTRACT

Among many problems in micro-grids is the voltage and frequency control in isolated mode especially during islanding process. Neural networks have been successfully used for character recognition, image compression, and stock market prediction, but there is no direct application related to controlling distributed generations of Micro-grid. For this reason, this work was decided on, with the aim of controlling diesel generator outputs. Firstly primary controlling quickly provides the required power of micro-grid in isolated mode. Then in next step controllable distributed generations play the role of secondary controllers. This work uses Artificial Neural Network (ANN) for considering of active and reactive power inter-effect on voltage and frequency. It examines the neural network algorithm that can be utilized for alleviating voltage and frequency issues of Micro-grid. MATLAB and Particle Swarm Optimization (PSO) are used for training neural network and simulating the Micro-grid model respectively. The Feed forward Back-propagation algorithm is used in this study and the Micro- grid consists of wind, solar, and diesel power generations, and battery energy storage system (BESS). Neural network indicates how much real and reactive power needed from each generator so as to improves the stability in the system..

Key words: Micro-Grid (MG), Particle Swarm Optimization (PSO), Distributed Generators (DGs), Artificial Neural Network (ANN).

INTRODUCTION

It is evident that the generated power in this country is inadequate and so, the utility company considers load shedding and restricted demand as a way out just as the government of the federation considered privatization of the energy sector as the last resort. Worst still, even under these conditions of load shedding and restricted demand, the integrity of the supplied power has always been questioned. Micro-grid systems can be integrated with renewable energy sources and meet the needs of a wide range of application in commercial, industrial and other critical applications such as running at hospitals, schools and military bases. Micro-grid will also be increasingly deployed in rural communities to meet their electricity needs. Independence is one of the advantages of Micro-grid. It offers more reliability and stability over a traditional central generation. Faults and load imbalances are a reality within electrical distribution systems.

There is a need of a controller to help maintain stability. This paper looks at the strategies for voltage and frequency stability control in distributed generation systems can mitigate the imbalances of the epileptic power supply in a micro-grid using artificial neural network (ANN). the strategies on the maintenance of power system stability on the existing electrical network as a micro grid. The application of Particle warm Optimization (PSO) - Artificial Neural Network (ANN) concept is considered. The parameters of the existing lines, transformers and loads are considered in the study with some adjustment and the conventional parameters for diesel generators, wind turbines, energy storage system and photovoltaic cells are considered.

This study does not seek to design and model a completely new micro grid. It uses operational and trained result to prove the frequency and voltage stability of the micro grid.

LITERATURE REVIEW

A micro-grid is a cluster of loads and micro sources operating as a single controller system that provides power to its local area. There are different micro-grid control strategy and power management techniques. In micro-grid, power electronics technologies (converters) are required to interface with the power network and its loads. In many of the cases, there is a DC voltage source (e.g. PV), which must be converted to an AC voltage at required frequency, voltage magnitude and phase angle. In these cases, the conversion will be preferred using a voltage source converter (VSC), using a possible pulse width modulation (PWM) to provide fast control of voltage magnitude.The stability issue in the micro-grid seems to be gaining its attention. The power system is chiefly the restructuring in the power system particularly when exposed to a severe disturbance. Typically, the aspect of reliable and stable power supply as per their load demands is the concern. Among various stability issues of micro-grid, maintaining voltage and frequency stability are considered in this work in course of islanding process.

PREVIOUS WORKS IN THE AREA OF STUDY

The first review was a thesis: “Micro-grid Modeling and Online Management” by Faisal A. Mohamed, (January 2008) of Helsinki University of Technology, Finland Control Engineering. This work developed a novel intelligent technique to manage the operation of MG units for residential or industrial utilization. Genetic algorithms (GAs) are used to find optimal settings of the MG units depending on detailed economic and environmental models. The objective is to develop an intelligent management tool, which can be used for environmentally constrained economic problems of the MG. The problem can be classified as a multi objective optimization and nonlinear programming problem. The purpose of the tool is to find the optimal amount of the generated power by minimizing the operating cost and the emission level simultaneously while satisfying the load demand and operational constraints but has limitation to DC micro-grid.

The second review was work: “Power System Stability for Micro-grid” by Ritwik Majumder, (February, 2010) of Queensland University of Technology, Queensland, Australia, Environmental Engineering. In this work an angle droop controller is used to share power amongst converter interfaced DGs in a micro-grid. As the angle of the output voltage can be changed instantaneously in a voltage source converter (VSC), the load sharing can be performed by drooping the converter output voltage magnitude and its angle instead of frequency. Based on this, a small signal model of the system is developed to tradeoff between power sharing and stability.

There are other works in the subject – area reviewed which for want of space cannot be included here but are duly referenced. They all are linked to maintaining stability in micro-grid but my interest and objectives with regard to this thesis are to contribute new scheme in the maintaining of power system in micro-grid.

MICRO-GRID SYSTEM STRUCTURE

In this study method 4 is applied where the particle swarm optimization neural network algorithm is used on which the Micro-grid consists of wind, solar, diesel power generations, and battery energy storage system. Neural network will indicate how much real and reactive power is needed from each generator. The diesel generators should smooth these disturbances by controlling its real and reactive power.

The system also includes two DG units, i.e., DG1 (80kWA) and DG2 (60kWA) on bus (B5) and bus (B10) respectively. DG1 is a synchronous rotating machine equipped with excitation and governor control systems. It is a diesel generator unit. DG2 utilizes a voltage-sourced converter (VSC) as the interface medium between its source and the power system. DG2 represents a dispatchable source with adequate capacity to meet the real/reactive power commands, within pre-specified limits, subsequent to disturbances. Such a dispatchable source may also include energy storage interfaced at the converter dc bus. DG2 provides control on its output real and reactive power components independently.

SYSTEM CHARACTERISTICS

Figure.1 shows the structure of the case study system which is a low voltage micro-grid connected to 11kV as a main grid by means of a 500kVA transformer. It represents a small community that consists of solar, wind, and diesel generations, battery storage and cumulated 3 variable loads. The system is a three phase balanced power system disconnected from the utility grid. As time progresses, the load demand changes. When the total load demand changes significantly, it might cause problems such as low and high voltage issues at the critical buses.

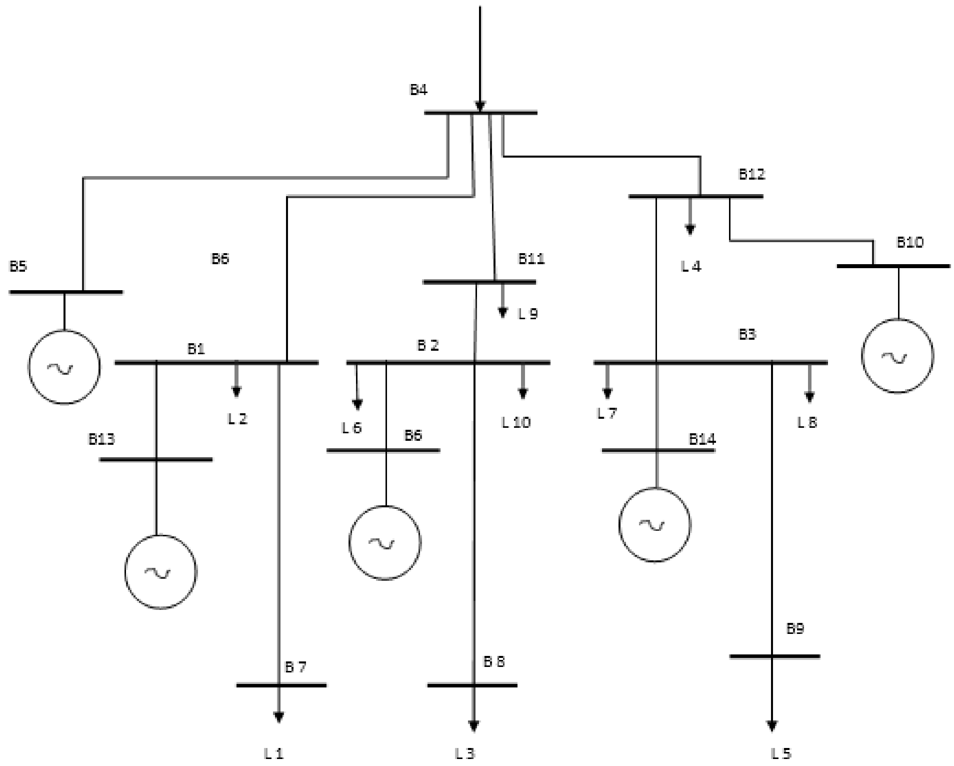

Figure 1. The Structure of the 14-Bus Micro-grid System

The purpose of this study is to improve on the stability of the Micro-grid. The diesel generations smoothed out these disturbances by controlling their real and reactive power outputs using a neural network algorithm. Neural network will provide how much real and reactive power is needed from each generator supplying power to the system. This study included low voltage issue, high voltage issue, and low and high voltage issue at the same time at the terminal of sensitive loads. The lower bound and higher bound voltage are considered 0.978 and 1.027 per unit respectively. The power factors of diesel generators were also considered; the desired range was from 0.85 to 0.89 per unit. The system voltage is at a distribution level with rated line to linevoltage is 415V on end of load point. The locations of the power generation are given in this study as shown figure 1 above.

Particle Swarm Optimization as an Optimization technique

The learning factors have significant effects on the algorithm convergence rate. The main steps for the proposed optimal BESS-based PSO algorithm technique were:

Step 1):- Initialize the parameters and iteration i = 1 with random position (xi) and velocity (Vi). Load shedding was set based on the measured power imported by the grid at the moment of islanding.

Step 2):- Start the particle j = 1 in the swarm.

Step 3):- Execute the objective functions for particle jth of iteration ith.

Step 4):- Find Pbest and Gbest for particle jth of iteration ith. If the fitness value of jth ≤ the best global fitness value, the program sets Pbest = f1 (xj,) and saves the best total cost (Pbest_CT) = f2 (xj.).

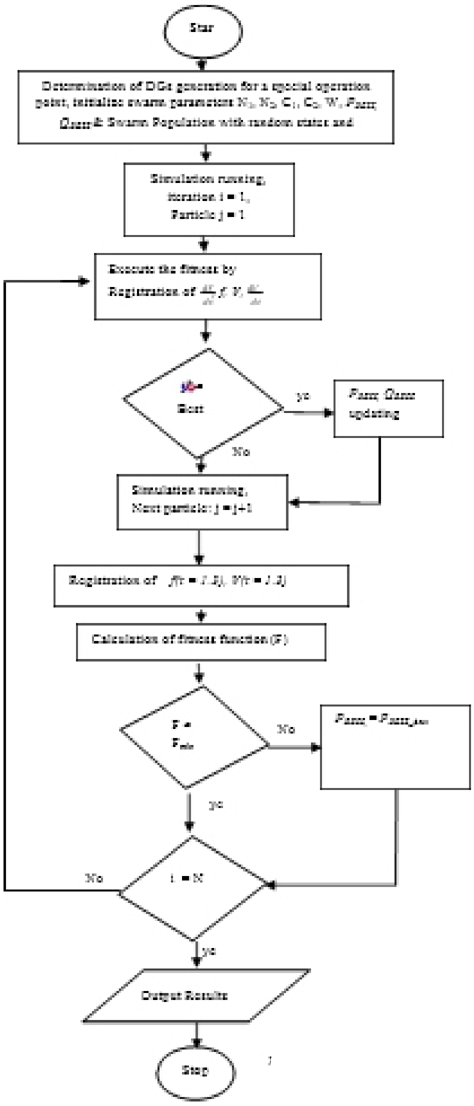

Figure. 2:- Generation of training data by PSO.

Step 5):- Increase particle jth by 1. Then, check the condition If particle jth +1 ≤ NP, go back to

Step 6):- Adjust Gbest of ith = the best values of Pbest at ith.

Step 7):- Increase iteration ith by 1. Then, check the condition if iteration ith +1 ≤ NI, go back to step 2) and update the new position (xi+1) and new velocity (vi+1) for the next iteration.

Step 8):- If iteration ith +1> NI, the process ends.

The overall flow chart of the optimal sizing of BESS based PSO with load shedding is shown in Fig. 2.

Table 1:- Generated PSO data for ANN training

	P	Q	V	kW/ph	kVar/ph
Gen 1	1	0.5597	1.018	-	-
Gen 2	0.9504	0.35	1.018	-	-
PV	0.00026	0.00048	0.9977	-	-
WT	0.00114	0.00134	0.9983	-	-
Battery	0.05408	0.01934	0.9907		
L1	0.34865	0.18023	1.0038	15	65
L2	0.06966	0.04496	1	36	14
L3	0.04537	0.02398	0.9978	15	69
L4	0.09024	0.01798	0.9977	80	40
L5	0.18091	0.04962	0.9831	80	35
L6	0.16291	0.03535	0.9838	25	12
L7	0.19582	0.02997	0.9867	25	5
L8	0.36253	0.14995	0.9832	90	20
L9	0.27325	0.22782	0.9992	5	1.2
L10	0.24189	0.10795	1.0031	7	2

Figure 3 shows that Slope of regression fit values measure the correlation between neural outputs and output targets. An R value 1 means a close relationship and 0 means a random relationship. This means that the closer the value of R to 1, more accurate the prediction with overall regression R = 0.99604 as in training i.e. learning weights of the ANN R = .099728; validationi.e. tuning the parameters (number of hidden units; architecture) R = 0.98802 and test i.e. the performance (generalization) of a fully-specified ANN R 0.9891.

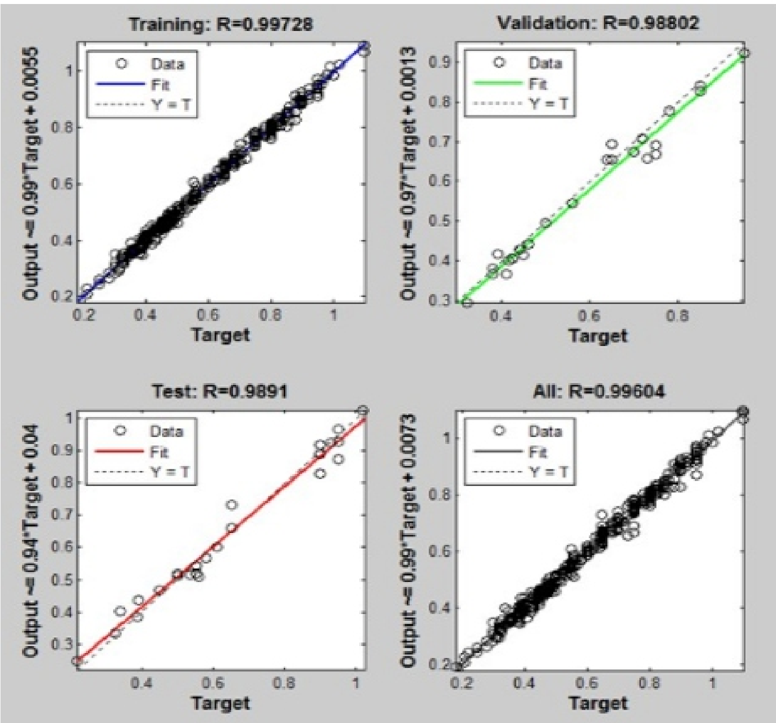

Figure 3: The training result for monitor of the 10 loads (Slope of regression fit).

CONCLUSION

This work considered control strategy for micro-grid by means of PSO algorithm technique trained on neural network. During islanding process or load changes in isolated mode at first BESS quickly absorbs this power then in the next step output is reduced gradually and the output of the controllable distributed generations is increased. Appropriate active and reactive power values of BESS are estimated using a MLP neural network according to - , f, V, - , in order to creation of database for training of neural network in 1000 different operation points, micro-grid is isolated from main grid and for each operation point, power injection values of BESS is registered due to the less voltage and frequency deviation using PSO algorithm technique. Based on the system condition, the amount of power to be generated by each DG is obtained by the neural network. The ANN trainer is created using MATLAB software employing with feed- forward and back propagation algorithm. ANN output is satisfactorily trained as confirmed by a mean-squared error (MSE) for training equal to 0.00898532 and for test error of 0.00045532. The ANN Controller shows effective improvement and changes in the output by tuning the values of KP and Ki than the conventional PI controller and thereby helps in improving the stability of the system. Simulation results verify the performance of this control strategy.

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Transient Analysis and Random Vibration Analysis of Titanium Wheel under Radial Load

Prof. Sandeep Sharma[*], Mohit Gaba[**], Narinder Singh[***]

[*]Associate Professor, Mechanical Engineering Department, Asra College of Engg. & Technology, Bhawanigarh (India)

[**] Assistant Professor, Mechanical Engineering Department, Asra College of Engg. & Technology, Bhawanigarh (India)

[***]Research Scholar, Mechanical Engineering Department, Asra College of Engg. & Technology, Bhawanigarh

A B S T R A C T

Although steel is the most common material used in wheel production which is an alloy of iron and carbon, but the term "alloy wheel" is usually reserved for wheels made from nonferrous alloys. Alloy wheels are wheels that are usually made from materials like aluminium, magnesium or titanium and mostly are mixtures of metal and other elements. They generally provide greater strength over pure metals, which are usually much softer and more ductile. Alloys are typically lighter for the same strength, provide better heat conduction, and often produce improved cosmetic appearance over steel wheels. In this research we proposed a detailed "Transient Analysis and Random Vibration Analysis of Alloy Wheel under Radial Load". During the part of project a transient and random vibration analysis of alloy wheel was carried out using FEA package. The 3 dimensional model of the wheel was designed using SolidWorks. Then the 3-D model was imported into ANSYS using the IGES format. The study of stress generation due to time varying load and vibration in the titanium alloy wheel is done in transit vibration and random vibration.

Keywords:-FEM, ANSYS, Transient analysis, random vibration

INTRODUCTION

Alloy wheels are wheels that are made from an alloy of aluminum or magnesium. Alloys are mixtures of metal and other elements. They generally provide greater strength over pure metals, which are usually much softer and more ductile. Alloys of aluminum or magnesium are typically lighter for the same strength, provide better heat conduction, and often produce improved cosmetic appearance over steel wheels. Although steel, the most common material used in wheel production, is an alloy of iron and carbon, the term "alloy wheel" is usually reserved for wheels made from nonferrous alloys. The earliest light-alloy wheels were made of magnesium alloys. Although they lost favor on common vehicles, they remained popular through the 1960s, albeit in very limited numbers. In the mid-to-late 1960s, aluminum-casting refinements allowed the manufacture of safer wheels that were not as brittle. Until this time, most aluminum wheels suffered from low ductility, usually ranging from 2-3% elongation. Because light-alloy wheels at the time that were often made of magnesium (often referred to as "mages"), these early wheel failures were later attributed to magnesium's low ductility, when in many instances these wheels were poorly cast aluminum alloy wheels. Once these aluminum casting improvements were more widely adopted, the aluminum wheel took the place of magnesium as low cost, high-performance wheels for motorsports. Alloy wheels were first developed in the last sixties to meet the demand of racetrack enthusiasts who were constantly looking for an edge in performance and styling. It was an unorganized industry then. Original equipment manufacturers soon realized that a significant market opportunity was being lost as car owners were leaving car show rooms with stock wheels and driving down to a dealer for fitment wit high pried custom alloy wheels. Since its adoption by OEM's, the alloy wheel market has been steadily growing.

1.2 Finite Element Methods (FEM)

To be competitive in a changing market it is necessary to deliver reliable products in the shortest period of time possible. Increasing competition and innovations in automobile sector tends to modify the existing products or replace old products by new and advanced products. Finite Element Analysis (FEA) was first developed in 1943 by R. Courant, who utilized the Ritz method of numerical analysis and minimization of variation calculus to obtain approximate solutions to vibration systems. Shortly thereafter, a paper published in 1956 by Turner established a broader definition of numerical analysis. The paper centered on the "stiffness anddeflection of complex structures". By the early 70's, FEA was limited to expensive mainframe computers generally owned by the aeronautics, automotive, defense, and nuclear industries. Since the rapid decline in the cost of computers and the phenomenal increase in computing power, FEA has been developed to an incredible precision. Present day supercomputers are now able to produce accurate results for all kinds of parameters. Before the advancement of personal computers, only few institutions were able to perform Finite Element Analysis, making the design process extensive and exclusive in the automobile and aeronautic industries. The Finite Element Analysis (FEA) or Finite Element Method (FEM) is a numerical technique, which could give near accurate solutions to complex field problems. Basically this method involves dividing the complex structures into known number of smaller structures or elements. This ability of the method is called discretization or meshing, which makes the technique more effective in analyzing irregular shaped structures in a variety of engineering problems. Mathematically it is nothing but representing most of physical problems in terms of mathematical models formed by differential and integral equations. Complexities such as irregular shape of the object or boundary conditions involved in the physical problems can make these equations almost impossible to solve directly. In this situation finite element analysis technique is adopted to obtain near accurate solution for the physical problem by approximately solving the governing equations, which could not be solved otherwise.

The traditional product development process is based on fundamental engineering equations and effective in analyzing regular shaped simple problems. However for complex physical problems the design process is more dependent on extensive testing, which normally makes the process expensive. The modern product development process with FEA technology does not eliminate the product testing process, but its ability to analyze complex physical problem easily and effectively can reduce the initial prototype testing in the design stages of the product development process. This makes FEA technology valuable in today's competitive industrial environment. Therefore in this research the solution is sought for a structural problem, originally designed by the traditional method. The following section discusses how the FEA technology is adopted in the product development process of the lock, which is originally designed by the traditional product development process. FEA uses a complex system of points called Needs which make a grid called a Mesh. This mesh is programmed to contain the material and structural properties which define how the structure will react to certain loading conditions.Nodes are assigned at a certain density throughout the material depending on the anticipated stress levels of a particular area. Regions which will receive large amounts of stress usually have a higher node density than those which experience little or no stress. Points of interest may consist of: fracture point of previously tested material, fillets, corners, complex detail, and high stress areas. The mesh acts like a spider web in that from each node, there extends a mesh element to each of the adjacent nodes.

1. LITERATURE REVIEW

Hardy et al. [1996] degrade the phase noise of quartz crystal oscillators under vibration, mainly due to the acceleration sensitivity of the quartz crystal element. It is shown that if a crystal mount resonance is excited by a random vibration profile then the phase noise close to the carrier, outside the random vibration profile, can be further substantially degraded. A consequence is that the vibration sensitivity would seem to increase rapidly at low vibration frequencies. For example, a crystal oscillator with a resonance at 1950 Hz subjected to a random vibration profile of 0.01 g2/Hz extending from 100 Hz to 3000 Hz compared with a profile of 100 to 500 Hz , where the resonance is not excited, can have over 40 dB degradation in the phase noise at 20 Hz from the carrier. The resonance level is shown to become non-linear with vibration power, possibly due to the large acceleration amplification of the resonance, 100 to 300 times. The vibration level where the resonance becomes non-linear varies by two orders of magnitude and starts as low as 0.0003 g2/Hz This phenomenon is demonstrated for four oscillators and investigated under varying acceleration levels in an attempt to quantify the nonlinear behavior. The nonlinear behavior of the resonance is believed to produce intermodulation of the mechanical vibration which leads to the degradation of the close to carrier phase noise.

Noori et al. [2000] observed that intelligent and adaptive material systems and structures have become very important in engineering applications. The basic characteristic of these systems is the ability to adapt to the environmental conditions. A new class of materials with promising applications in structural and mechanical systems is shape memory alloy (SMA). The mechanical behavior of shape memory alloys in particular shows a strong dependence on temperature. This property provides opportunities for the utilization of SMAs in actuators or energy dissipation devices. However, the behavior of systems containing shape memory components under random excitation has not yet been addressed in the literature. Such a study isimportant to verify the feasibility of using SMAs in structural systems. In this work a nondeterministic study of the dynamic behavior of a single-degree-of-freedom (SDOF) mechanical system, having a Nitinol spring as a restoring force element is presented. The SMA spring is characterized using a one-dimensional phenomenological constitutive model based on the classical Devonshire theory. Response statistics for zero mean random vibration of the SDOF under a wide range of temperature is obtained. Furthermore, nonzero mean analysis of these systems is carried out.

China et al. [2006] established a numerical model for new grain refinements of aluminum alloys automobile wheel, based on the traditional solidification mechanism. It is assumed that the constitutional under cooling generated by growth of a grain is equivalent to the under cooling required for nucleation of another adjacent grain; and the distance between nucleation events is defined as the relative grain size in the final microstructure; the negative thermal gradient and the latent heat at the grain-liquid interface are negligible in comparison to the amount of constitutional under cooling; the thermal physical parameters are fixed. On the basis of numerical model results, the constitutional under cooling and the relative grain size of the grain refinements have been calculated. The nucleation under cooling of the new grain is about 0.5- 1.0K, which is lower than traditional aluminium alloys by 0.3-0.5K. The numerical model results can be used to investigate the grain refinement mechanism, and the new grain refinements can be used to produce aluminium alloys automobile wheel.

Han et al. [2006] studied the microstructure and properties of wheels from a low pressure casting A356 alloy. Present studies focus effect of intermetallic phases on mechanical properties of cast A356 alloy wheels. It was found that each alloy has different types of intermetallic phase in the microstructure. Also, low pressure casting A356 alloy wheel were remelted and tested for mechanical properties. It shows that 5976 alloy containing higher iron shows the decreased in strength and elongation. However, the hardness is higher than 5975 alloy. This is mainly due to the presence of brittle P-AlSiFe phase in the microstructure. The large size of 13-AlSiFe phase was usually precipitated in the slow solidification area.

Hsu et al. [2006] investigate the effects of board-level drop test based on the support excitation scheme incorporated with the sub model technique for stacked die packages. This paper also demonstrates the transient dynamic response for lead-free SAC405 (95.5Sn4Ag0.5Cu) solder balls subject to JEDEC pulse-controlled board-level drop test standard JESD22-B110A.

Condition B[1]. To evaluate the structure of the interested area, a strip model sliced from the full test vehicle is used in this research. In addition, the sub model region is particularly chosen with strip model by performing the cut boundary interpolation. The envelope of equivalent stress for the outermost solder joint off the end of the strip model is plot to show the potential solder failure mode and mechanism. The cut boundary of sub model is verified and the mesh density of sub model is examined. For a refinery mesh of sub model, parametric studies are carried out to study the reliability of the outermost solder joint, and the results are summarized as design rules for the development of stacked-die packages.

Tsipas et al. [2007] observed systematic material failure of wheel suspension assemblies on several combat vehicles after about 10 years of continuous operation under severe cross-country route and environmental conditions. The present study focuses on the failure of the trail wheel trunion, cast from an Al-alloy. Visual inspection, macro graphic examination and microscopic observations revealed that cracking was initiated at the inner micro machined surface of the alignment lugs and propagated towards the external surface, during long term vehicle operation. Similar findings were observed on the conjugate trunion piece, where inter granular cracking was extended in a significant depth beneath the fracture surface. Failure is attributed to the existence of a stress gap, due to the different fixation configurations of the attachment pin on the alignment lug.

Cockcroft et al. [2007] developed a mathematical model of the low-pressure die casting process for the production of A356 aluminum alloy wheels to predict the evolution of temperature within the wheel and die under the auspices of a collaborative research agreement between researchers at the University of British Columbia and a North American wheel casting facility. The heat transfer model represents a three-dimensional, 30◦ slice of the wheel and die, and was developed within the commercial finite-element package, ABAQUS. Extensive temperature measurements in the die and in the wheel taken over several cycles in the casting process were used to develop key process boundary conditions and validate the model. The predicted and measured temperatures agree very well, with the maximum difference less than 20 ◦C at the majority of locations examined. A heat flux analysis conducted with the model has identified the complex path that the heat follows within the die and wheel during the solidification process. A solidification path analysis conducted with the model showed the presence of a hot spot in the rim/spoke junction area, which was confirmed by the observation of macro-porosity in a sectioned wheel.

2. CAD MODELING

SOLIDWORKS is solid modeling CAD (computer-aided design) software that runs on Microsoft Windows and is since 1997 produced by DassaultSystèm. SOLIDWORKS Corp., a subsidiary of DassaultSystèms, S. A.(Vélizy, France). SOLIDWORKS is currently used by over 2 million engineers and designers at more than 165,000 companies worldwide.

Solidworks is used for the 3D CAD modeling of Alloy Wheel.

The steps to complete the model are as follows:

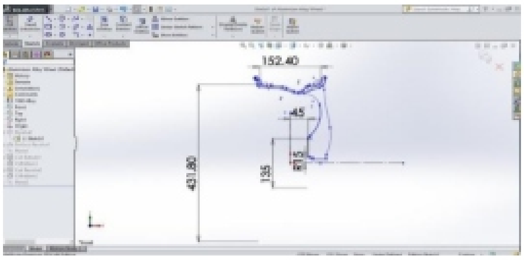


Figure: - 1 profile of alloy wheel

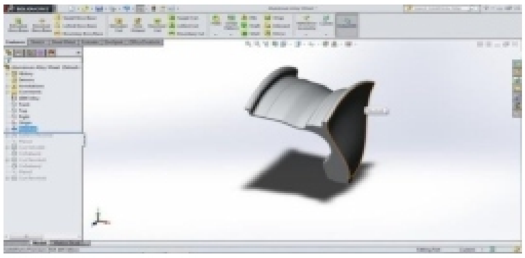


Figure: - 2 Revolve tool used

Draw the sketch profile of alloy wheel with the parameters of Rim diameter - 431.8mm, Rim width – 152.4mm, offset- 45mm, PCD- 100mm and Hub diameter- 135mm.

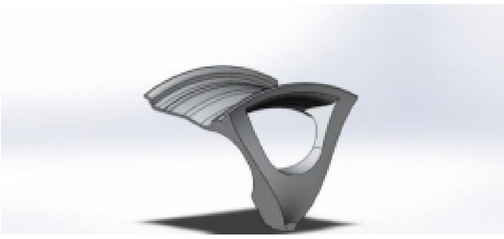


Figure: - 3 cut the material

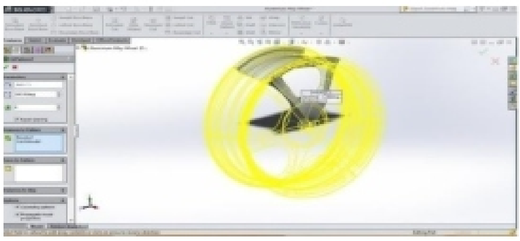


Figure: - 4 Circular pattern command

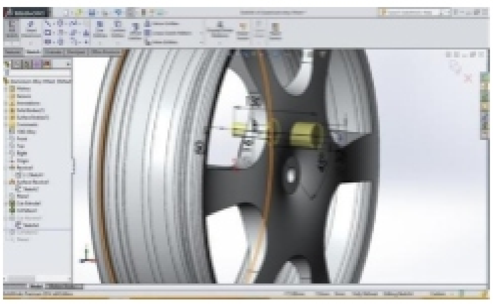


Figure: - 5 Make holes in alloy wheel

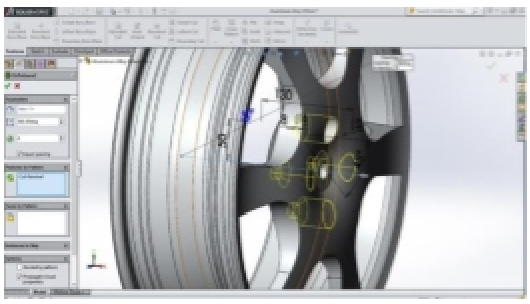


Figure: - 6 make all holes in alloy wheel

Now the solid works model will be saved as parasolid format (universal format) so that it is ready for data interoperability which means that the model can be opened and analyzed in ANSYS software.

Figure: - 7 Alloy Wheel

3. RESULTS AND DISCUSSIONS

We have successfully analyzed structurally the alloy wheel with the time varying pressure with ANSYS software and calculate maximum stress and deformation. We also study the stress occurs due to the random vibration. For this purpose we will select materials like Titanium and study the effect on stress and total deformation occurs on the titanium wheel is calculated. we also calculate the stress and total deformation with the time varying pressure and the graph will be plotted accordingly

1. For Titanium

A. Time varying from 0s to 10s with varying pressure-

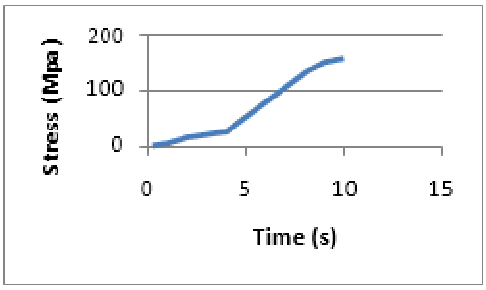


Figure:-8(a) Variation of Stress w.r.t time

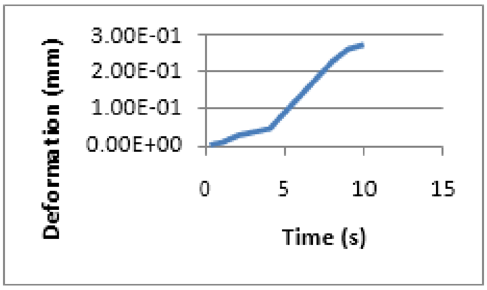


Figure:-8(b) Variation deformation w.r.t Time

B. For time varying 0s-1s with varying pressure-

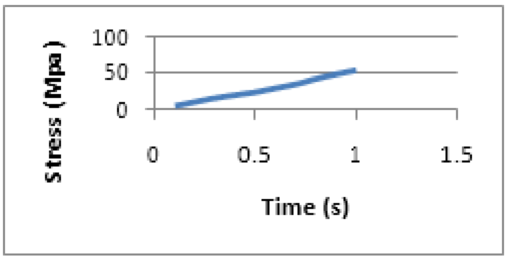


Figure: -9 (a) Variation of Stress w.r.t Time

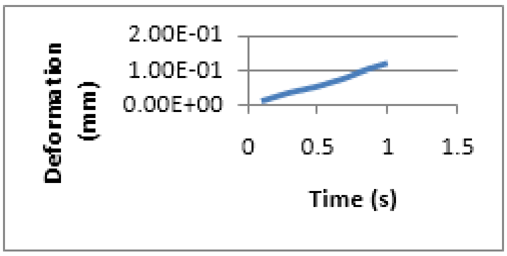
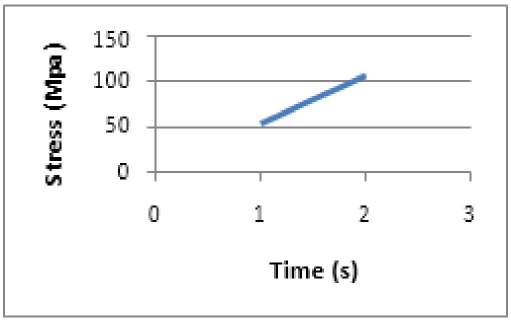


Figure: - 9 (b) Variation of Total Deformation w.r.t Time

C. Time varying 1s-2s with varying pressure-



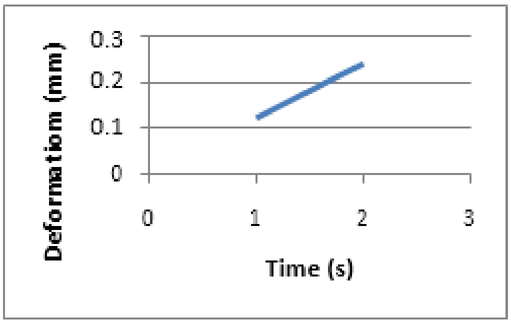
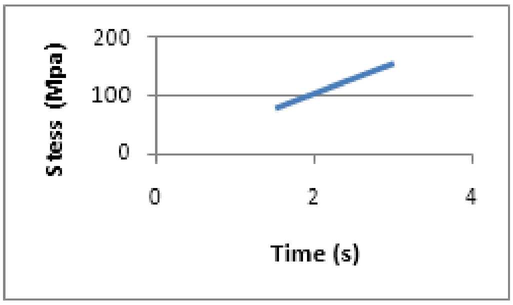


Figure: - 10 (a) Variation of Stress w.r.t Time Figure: - 10 (b) Variation of Total deformation w.r.t Time

D. Time varying from 2s-3s with varying pressure-



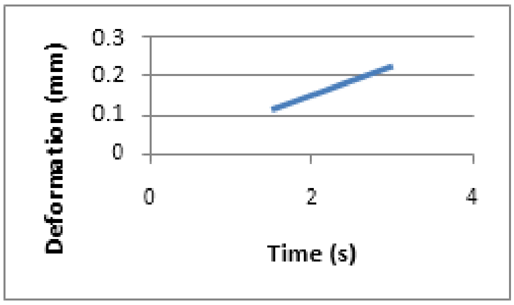


Figure: - 11 (a) Variation of Stress w.r.t Time Figure: - 11 (b) Variation of Total deformation w.r.t Time

4. CONCLUSION

The effect of Transient (Time Varying) load and the stress generated due to the vibration on an alloy wheel is calculated and studied for Titanium materials.

During the study of stress generation due to time varying load and vibration in the titanium alloy wheel the stresses is generating slowly by the variation in time. The maximum stress is generated in Titanium alloy is 157.44 Mpa. The vibration is generated in the Titanium alloy wheel at maximum Acceleration is [$(mm/s^2)^2/Hz$] 5.00E+06. The maximum stress is generated due to random vibration is 1.441e-006 Mpa.

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Investigation Into Fouling Factor in Compact Heat Exchangers

Masoud Asadi[*], Dr Ramin Haghighi Khoshkho[**]

[*] Mechanical department of Azad Islamic University, Hesarak Ave, Tehran, Iran

[**] Department of Mechanical Engineering & Energy engineering, Power and Water University of Technology, Tehran, Iran

ABSTRACT

Fouling is a generic term for the deposition of foreign matter on a heat transfer surface. Fouling potentially affects all types of heat exchanger. Deposits accumulating in the small channels of a compact heat exchanger affect both heat transfer and fluid flow. Fouling deposits constricting passages in a compact heat exchanger are likely to increase the pressure drop and therefore reduce the flow rate. Reduced flow rate may be a process constraint; it reduces efficiency and increases the associated energy use and running costs. Maintenance costs will also increase. Fouling remains the area of greatest concern for those considering the installation of compact heat exchangers. The widespread installation of compact heat exchangers has been hindered by the perception that the small passages are more strongly affected by the formation of deposits. In this paper different types of fouling and treatment are presented.

1. INTRODUCTION TO FOULING IN COMPACT HEAT EXCHANGERS

Obviously, compact heat exchangers are unsuitable for fluids containing large particulate material or debris. However, the high shear forces, low wall superheat and homogeneous flow distribution typical of compact heat exchangers reduce the formation and adhesion of deposits on the heat transfer surfaces. Also, the use of more corrosion resistant materials with smoother heat transfer surfaces further reduces the formation of deposits.

Section .2 examines the generic types of fouling that can occur in heat exchangers and outlines possible solutions. Section.3 examines the effects of fouling in more detail for different exchanger designs and section .4 provides further information on minimising the risk of fouling at the specification stage. It is assumed that the specifier of the heat exchanger will have knowledge of the nature of the process stream. However, this will not always be the case, as plant and stream changes can occur sometime after units have been installed.

The adoption of heat exchangers has been affected by the perception that those with small channels are likely to foul. Care should be taken when selecting compact heat exchangers for use in situations where mechanical cleaning is impossible. In these cases provision for chemical cleaning must be made. However, gasketed plate heat exchangers are frequently easier to clean than shell and tube types, provided other parameters permit their use.

There are two primary problems associated with the small flow passages used in most types of compact heat exchanger:

- The possibility of the heat exchanger acting as a filter for large particles, with these particles forming a filter cake at the inlet to the exchanger.
- The rapid increase in flow resistance resulting from the deposition of only a small thickness of material on exchange surfaces that might pass unnoticed in conventional shell and tube heat exchangers.

Figure.1 - Crystalline (Milkstone) Fouling on a Plate and Frame Exchanger Plate from the Dairy Industry

The risk of partial blockages turning into complete blockages is also very much higher for compact heat exchangers than for shell and tube heat exchangers, and the difficulty of clearing such blockages, either by mechanical or chemical treatment, is also greater. However, the ability of a compact heat exchanger to filter out material has proved useful in certain applications. In some gas-gas units, the small channel size has caused fibres to collect on the front face of the heat exchanger, instead of in the core where they would be more difficult to remove.

The effect of fouling depends on the deposit location. This, in turn, depends on the fouling mechanism and so on fluid composition. The effects of fouling are likely to be more important for fluid flow than for heat transfer.

For a fluid flow the factors that influence the effect of fouling are:

- The narrowness of the passages, which are relatively easily blocked by particles and fibres.
- The fact that only a small amount of material is required to achieve blockage.

- The difficulty of removing any blockage (although this depends on experience). Judging the effects of fouling on heat transfer need to take into account:
- The thickness of the deposit, its nature and the area covered.
- The relationship between the clean heat transfer coefficient and deposit resistance.
- The implications for design fouling resistance and the irrelevance of TEMA values.

2. TYPES OF FOULING AND TREATMENT

For convenience, fouling is generally classified under one of the following six headings, depending on the mechanism causing the deposition:

- Crystallisation or Precipitation Fouling.
- Particulate Fouling (Silting).
- Biological Fouling.
- Corrosion Fouling.
- Chemical Reaction Fouling.
- Freezing or Solidification Fouling.

2.1 Crystallisation or Precipitation Fouling

Crystallisation or precipitation fouling occurs when a solute in the fluid stream is precipitated out and crystals are formed, either directly on the heat transfer surface or in the fluid, and subsequently deposited on that surface. When the fluid concerned is water, calcium or magnesium salts are deposited, frequently referred to as scaling. Figure.1 shows a plate fouled by crystalline calcium phosphate deposits.

For normal solubility salts (e.g. sodium chloride), this type of fouling decreases with increasing heat transfer surface temperature, as the solubility increases. For the more troublesome inverse solubility salts (e.g. calcium sulphate, calcium phosphate, calcium silicate, calcium carbonate, magnesium hydroxide and magnesium silicate), the solubility decreases with increasing temperature. Hence, these salts are prone to forming deposits on surfaces where heat is transferred to water, either during cooling or evaporation.

It is important to identify the highest cooling water temperature that is likely to occur in a heat exchanger with narrow channels to determine the appropriate water strategy.

Solution

Crystallisation or precipitation fouling is normally avoided either by pre-treating the fluid stream (e.g. by adding acid to cooling water to remove bicarbonate) or by the continuous addition of chemicals to reduce or eliminate deposit formation.

If deposits do form, they can often be removed by treatment with appropriate chemicals, e.g. by adding acid to remove carbonates. Care must be taken to ensure that the cleaning chemicals are compatible with the construction materials used for the exchanger.

Mechanical methods, such as the high-pressure lances that are often used to clean shell and tube heat exchangers, are unlikely to be of use for compact heat exchangers because of their small passage size.

2.2 Particulate Fouling (Silting)

Particulate fouling (or silting) occurs when solid particles from the fluid stream are deposited on the heat transfer surface. Most streams contain some particulate matter, originating from a variety of sources. Small particles are less likely to be removed from the surface than large ones. The combination of particles with condensation or other sticky forms of fouling can produce a deposit that is much more adhesive and difficult to remove than the individual components on their own. An example would be a combination of paper fibres and polymer adhesive from ink in a printing works heat recovery unit.

A particulate deposit may also provide a mechanism for keeping a surface wet. This may have implications for corrosion (e.g. the formation of an acid condensate from combustion gases).

Solution

Purely particulate fouling can be reduced by the use of sufficiently high fluid velocities. If the deposit also contains matter that acts as an adhesive, a solvent or other chemical treatment will be required to remove the adhesive. Chemical dispersants that affect the surface charges on solids can also assist in avoiding deposit formation.

Mechanical removal, e.g. by brushes, may be feasible, if access is available.Air rumbling, i.e. the temporary addition of air or of nitrogen to the liquid stream is frequently used to dislocated particulate or biological deposits.

Larger particles can easily be filtered out, and a suitable strainer could be located upstream of a compact heat exchanger where such particles are expected. The application of a severe pressure pulse can remove silting, but its effect on the mechanical strength of the exchanger must be considered.

Several other factors alleviate fouling in compact heat exchangers. The use of corrosionresistant materials minimises fouling by upstream corrosion products and the specific design of compact heat exchangers gives high wall shear stresses. Designers should ensure that there are no flow dead spots.

2.3 Biological Fouling

The deposition and growth of organisms on surfaces cause biological fouling. The organisms most likely to cause problems in compact heat exchangers are bacteria, which can thrive even if the concentration of nutrients in the water is less than one part per million.

Bacteria grow over a wide range of temperatures. Bacterial growth may physically constrict flow passages or can generate a corrosive environment (e.g. sulphate reduced to hydrogen sulphide is corrosive to most materials, including common stainless steels).

Solution

Biological fouling is best controlled by treatment with biocides. Non-oxidising biocides are normally alternated to prevent the development of bacterial deposition. Certain biocides kill the bacteria, but do not remove the biofilm accumulation, but some are available with detergent properties that disrupt the film. Oxidising biocides, such as chlorine and ozone, oxidise the biofilm as well as killing the bacteria and may therefore require higher concentrations to be effective.

Compared with a conventional shell and tube exchanger, the relatively low surface area and the lower fluid inventory in a circuit with a compact heat exchanger should reduce the amount of biocide required. The well-defined flow in the small channels also aids rapid diffusion of the treatment chemical to the biofilm.

Figure 2 - Reaction Fouling (Protein Deposition) on a Plate and Frame Exchanger Plate

2.4 Corrosion Fouling

Corrosion fouling results from either a chemical reaction involving the heat transfer surface, or the transportation of corrosion products from elsewhere in the circuit and their deposition in the heat exchanger. Corrosion can also take place under the deposits, e.g. as a result of the formation of electrolytic oxygen concentration cells.

Solution

Corrosion fouling is best minimised at the specification stage by choosing materials that are resistant to corrosion in the fluid stream whenever possible. Alternatively, it is possible to dose with corrosion inhibitors, although the environmental impact of this approach must be considered. Cathodic protection can also be used, but care must be taken to ensure that the conditions do not form cathodic scales (calcium and magnesium salts) in hard waters and brines.

If a stainless steel heat exchanger is stored in a moist, salt-laden environment, measures should be taken to protect the surfaces. Amounts of salt as low as 1.0 mg/lcould result in stress corrosion cracking.

Compact heat exchangers are usually made of the more corrosion-resistant materials. Several types have nodissimilar metals or other materials present, making corrosion attack on the heat exchanger surfaces predictable, unless unforeseen impurities are present in the fluid streams.

2.5 Chemical Reaction Fouling

Chemical reaction fouling occurs when one or more constituents in the process fluid react to form a viscous or solid layer on the heat transfer surface, which is not itself involved in the chemical reaction. Such reactions are mostly polymerisations, and the deposit that is initially formed may turn from a tar to a hard coke or similar material that is more difficult to remove. Figure.2 shows protein fouling of a plate exchanger from the dairy industry.

Solution

The rate of chemical reactions increases exponentially with temperature, making it possible to minimise chemical reaction fouling by careful control of fluid and surface temperatures and by reducing residence times at high temperatures. Temperatures should not be increased to achieve the required heat transfer as this will make the fouling problem rapidly worse. It should be much easier to control chemical reaction fouling in a compact heat exchanger than in a conventional shell and tube exchanger because of the high degree of temperature control and low residence times. Compact heat exchangers have lower hold-up and residence times than conventional shell and tube exchangers.

2.6 Freezing or Solidification Fouling

Freezing or solidification fouling occurs when the temperature of the process fluid is reduced sufficiently to cause freezing at the heat transfer surface.

Solution

This type of fouling is the easiest to control, particularly in compact heat exchangers, where the small mass and low fluid inventory allows rapid clearance of the fouling by increasing the temperature to melt the deposit. In some cases, channels may be incorporated in the exchanger to allow a hot fluid stream to be introduced to melt material, such as hydrates. Compact heat exchangers offer a closer temperature approach and greater control over stream temperature.

3. THE FOULING RESISTANCE (RF)

In the thermal design of heat exchangers, fouling is conventionally taken into account by using an additional thermal resistance value, Rf, called the 'fouling factor' or 'fouling resistance', when calculating the overall heat transfer coefficient. Fouling reduces the overall heat transfer and, for a given duty, extra surface has to be provided to ensure that the required heat transfer is achieved.

In most cases fouling resistance is time dependent, with zero fouling initially. Frequently fouling resistance builds up to an equilibrium point where the rate of foulant removal is equivalent to the rate of deposition. Depending on the value of this 'asymptotic' fouling resistance, this may or may not allow continuous operation without cleaning. Alternatively, fouling resistance may continue to increase necessitating a cleaning action at some point.

Thermal resistance values are often taken from the standards recommended by TEMA. These are dedicated to shell and tube heat exchangers and, as such, are generally not applicable to compact heat exchangers. Using the TEMA values is likely to result in excessively high additional surface requirements. This is because the implied deposit thickness may give very high pressure drops in small channels. It is generally found that much lower fouling resistances than those recommended by TEMA can be used for plate and frame heat exchangers. Measures such as filters to avoid compact heat exchanger blockages have encouraged some industries (e.g. the cryogenics industry) to adopt fouling resistance values of zero. Some manufacturers may add 10 - 25% extra surface to allow for uncertainties in design codes and other factors, of which fouling may be one. This should not be used as an excuse to reduce the flow velocity.

3.1 Fouling in Plate and Frame Exchangers

Plate and frame heat exchangers were originally developed for the dairy industry. However, their application in the chemical process industry is increasing rapidly, where they begin to replace tubular heat exchangers in several traditional applications. While there is plenty of information about the governing equations for clean operation, information for fouling conditions is scarce. As shown in the following equation the percentage excess surface area increases with increasing clean heat transfer coefficient for a given heat duty.

$$\frac{A_f}{A_c} = 1 + U_{clean} R_f$$

Where
Af : is the surface area after fouling
Ac : is the clean surface area
Uclean : is the clean heat transfer coefficient
R f : is the fouling resistance

This puts a heavy penalty on compact heat exchanger types such as plate and frame heat exchangers if, because of ignorance or because of cautiousness, the TEMA fouling resistances for shell and tube heat exchangers are used. Typical clean overall heat transfer coefficients for plate and frame heat exchangers are about 3000 W/m2K, for shell and tube heat exchangers about 1000 W/m2K. A design fouling resistance of 0.3 m2K/kW corresponds to 30% overdesign for a shell and tube heat exchanger and to 90% overdesign for a plate and frame heat exchanger. Most manufacturers of plate and frame heat exchangers recommend that the excess surface should not exceed 25% of the heat transfer surface area calculated for the clean duty.

The fouling resistances listed in Table.1 have been recommended for plate and frame heat exchangers. Due to the non-uniformity of flow distribution and deposit formation, measured pressure drop increases are significantly higher than values predicted using an average deposit thickness calculated from the fouling resistance.

Table 1 - Fouling Resistances for Plate and Frame Heat Exchangers

Fluid (Water)	Fouling
Demineralised	0.009
Hard	0.043
Soft	0.017
Treated cooling	0.034
Coastal sea	0.043
Ocean sea water	0.026
River water	0.043
Engine jacket	0.052
Lubricating oil	0.017 - 0.043
Vegetable oil	0.017 - 0.052
Organic solvents	0.009 - 0.026
Steam	0.009
General process	0.009 - 0.052

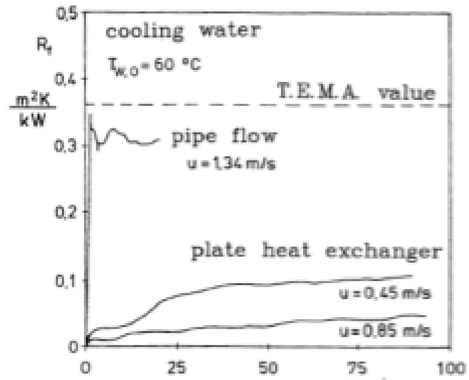

Figure 3 - Comparison of Fouling in Plate and Frame, and in Shell and Tube Heat Exchangers (after Cooper)

Effect of Process Parameters on Fouling

Cooper[2] investigated cooling water fouling using a plate heat exchanger. The water was chemically treated before entering the heat exchangers. Some of the important results of this investigation are given in Figure 3.

The fouling resistance in the plate and frame heat exchanger is significantly lower than in the shell and tube heat exchanger, despite the typically lower flow velocities. If the flow velocity is increased, the fouling resistance decreases similarly as it is found for shell and tube heat exchangers. This is also demonstrated in Figure.4 which shows the asymptotic value as a function of the surface temperature halfway up the plates.

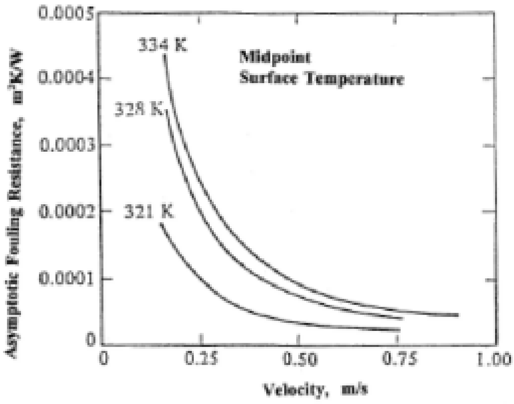

Figure.4 - Fouling Resistance in a Plate and Frame Heat Exchanger as a Function of Flow Velocity and Temperature

Novak[3] studied the fouling behaviour of Rhine River water near Mannheim (Germany), and of Öresund seawater in Sweden. For both waters, mainly biological fouling was observed. The fouling resistances increased almost linearly over the period observed. Table.2 summarisesthe effects of flow velocity on fouling rates.

Table 2 - Fouling Rates of Rhine River Water for a Surface Temperature of 25°C[3]

Type	u m/s	t Pa	$dR_f/dt\ 10^4 m^2 K/kWh$
Plate heat exchanger	0.13	6.7	7.4
Plate heat exchanger	0.19	14.5	4.3
Plate heat exchanger	0.77	190	0.6
Spiral plate exchanger	0.43	7.5	5

For constant flow velocity, Novak found that maximum fouling occurred at a surface temperature of about 35°C, due to the preferred living conditions of biological matter. Bansal and Müller-Steinhagen[4-6] investigated pure crystallisation fouling from CaSO4 in various plate heat exchangers. The rate of deposition increases with increasing wall temperature and bulk concentration and decreasing velocity. With increasing flow velocity, both the initial fouling rate as well as the absolute value of the fouling resistance decreases. Due to blockage of the outlet flow distribution area, the increase in pressure drop may be significantly higher than the increase in thermal fouling resistance. Chemical reaction fouling is strongly affected by the surface temperature that determines the reaction rate.

EFFECT OF PLATE DESIGN

Two low velocity zones exist in the plate channels, opposite to the inlet and outlet ports. In these zones, shear forces are at a minimum and the wall temperature is close to the temperature of the heating medium. Both conditions promote the formation of deposits. The extent of the stagnant zones depends on the design of the flow distribution section. It decreases with increasing flow velocity.

Kho [7] studied the various possibilities of providing excess heat transfer surface area for fouling. Figure.5 shows that minimum fouling occurs if the 20% excess surface area is provided by a two- pass arrangement of the original plates, followed by the use of larger plates with the same width, followed by larger plates with standard width/height ratio. The poorest performance is obtained when the excess surface is simply added as parallel plates. The actual plate geometry (angle, amplitude and wavelength of corrugations) affects the formation of deposits. Delplace et al. [8] found that deposition from whey protein solutions on herringbone plates is only half of that of straight corrugations, for otherwise identical conditions.

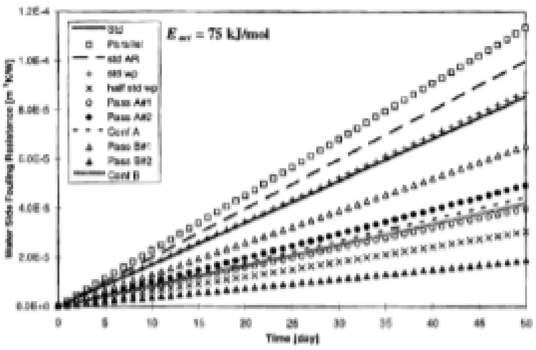

Figure.5 - Effect of Plate Arrangement on Fouling (After Kho)

Plate heat exchanger designs with extra-wide plate gap are available for applications with significant particulate content or severe fouling.

For all types of fouling, the delay time decreases with an increase in surface roughness. Heat exchanger plates usually have smoother surfaces than pipes, because of the manufacturing process itself and because the lower area requirement allows more expensive surface preparation. Electropolished plates with a surface roughness below 0.5 μm are commercially available, and are commonly used in food processing industries. Investigations with plate surfaces modified by Magnetron Sputtering, Physical Vapour Deposition and other technologies which can provide low surface energies are presently underway[9-10].

3.2 Fouling in Plate-Fin Heat Exchangers

Plate-fin heat exchangers are brazed/welded compact heat exchangers with a heat transfer surface density of about ten times that of tubular heat exchangers. Typical applications are cryogenic, chemical/petrochemical and hydrocarbon offshore installations. Molecular sieves and 100 μm filters are used in cryogenic installations to remove particulate matter or components that may freeze-out on the heat transfer surfaces.

Systematic investigations have been performed on particulate fouling[11] and on river water fouling[12].

For 3 μm ferric oxide particles suspended in water, no blockage of plain fin or wavy fin channels was observed. Wavy fin channels fouled more than plain fin channels. All experiments showed asymptotic behaviour. Higher deposition rates were obtained for non isothermal conditions and at higher bulk temperatures. Maximum deposition occurred at a Reynolds number of about 1500.

Fibrous and biological material partially blocked the inlet of the aluminium plate-fin test sections when used with river water that was filtered through a 1 mm mesh. Some deposition was found at locations where corrosion of the aluminium had occurred. In the wavy fin test section, a thin, uniform deposit of fine mud was observed. Pressure drop for the plain finning increased linearly with time, whereas asymptotic behaviour was found for the wavy finning. The initial slope of the relative pressure drop versus time curves was 5.8x10-8 s-1 for the plain fins and 1.71x10-7 s-1 for the wavy fins. For the latter, an initial deposition rate of 4.8x10-12 and an asymptotic fouling resistance of 6x10-6m2K/W were measured.

3.3 Fouling in Printed Circuit Heat Exchangers

The passages in printed circuit heat exchangers are typically between 0.3 mm and 1.5 mm deep. This specific design leads to volumetric heat transfer areas of 500-2,500 m2/m3, which is an order of magnitude higher than shell and tube heat exchangers.

Two sets of experiments are described by Kew[13] to compare the fouling related drop in performance of a printed circuit heat exchanger and of a double pipe heat exchanger:

1. Cooling water treated against corrosion, scale formation and biofouling, and with 0.5/1.0 mm strainers to reduce particulate fouling. For operating times of 500-660 hours, no change in thermal effectiveness was observed for the printed circuit heat exchanger, but the pressure drop increased by up to 55% due to the deposition of particulate material. The addition of a stainless steel mesh insert for the removal of fibrous material significantly reduced the increase in pressure drop. No deposition was observed in the parallel double pipe heat exchanger.
2. Cooling water treated against corrosion, biofouling and particulate fouling, but supersaturated to induce scaling. In tests between 100-290 hours, the thermal effectiveness again remained constant. The printed circuit heat exchanger pressure drop increased by up to 30% due to the formation of calcium carbonate and calcium phosphate. Pressure drop and thermal effectiveness in the double pipe heat exchanger remained constant. These experiments suggest that thermal effectiveness in printed circuit heat exchangers is not linearly related to pressure drop and that fouling must be carefully considered when selecting printed circuit heat exchangers.

Where printed circuit heat exchangers have been used for gas cooling using sea water, 200µm strainers have been installed upstream of the heat exchanger and chlorine added to counter biofouling. No operational problems have been reported.

Another application involved the heating of tail-gas in a nitric acid plant using condensing steam; after 18 months of operation, no indication of channel blockage could be detected.

3.4 Fouling in Polymer Compact Heat Exchangers

Polymer heat exchangers are used for low pressure operations involving corrosive gases or liquids. The low surface energy and the smooth surface of their construction materials (polypropylene, fluoropolymer etc.) reduce the stickability of most deposits. Since clean heat transfer coefficients are already low (150-250 W/m2K), these heat exchangers react less sensitively to additional fouling resistance than metallic heat exchangers.

4. PREVENTING FOULING EFFECTS

4.1 Design Stage

Identify at an early stage the extent to which process streams are likely to cause fouling. The following points give general guidance.

Circuit Configuration

Closed loops are unlikely to present significant fouling problems. Working fluids in refrigeration or power cycles, for example, should not cause any fouling in a well-engineered and maintained system.Open loops are prone to fouling, and may require the installation of filters to remove particles, fibres etc., as well as regular chemical treatment to prevent biological growth, the deposition of scale, and corrosion. In open systems, check the possibility of using selfcleaning strainers and of installing systems for biocide dosing, the application of scale inhibitors, etc., to control fouling.

Once-through streams need to be examined on a case-by-case basis and appropriate action taken if the stream warrants it. If water treatment is constrained by environmental concerns, consider installing an untreated primary cooling water circuit with a secondary clean circuit serving the plant. The other benefits of compact heat exchangers may make this worthwhile. Where a closed cycle system is not an option, consult with the equipment supplier(s) and give detailed consideration to:

- Fouling margins.
- Optimal flow rates.
- Control of heat exchanger operation.
- Upstream fouling prevention.
- In-exchanger fouling control/removal.

Alternatively consider a specific compact exchanger design able to handle the fouling projected.

Performance Monitoring

On larger installations, or where an exchanger duty is critical for a process, exchanger monitoring can give early indication of cleaning thresholds or failure conditions. Monitoring can either be continuous or intermittent as necessary. Progressive fouling will become evident by increases in the pressure drop through the heat exchanger. It is also essential to measure the stream flow rate because a pressure drop increase may be compensated by reduced flow. Inlet and outlet stream temperatures may also be measured. In some cases it may be useful to calculate heat transfer coefficients on a regular basis from the parameters measured above.

Particulate Fouling

Reputable equipment suppliers should know the tolerance of their heat exchangers to particulate fouling. If they recommend filtering down to 100 microns, accept this. Subsequent problems are likely to be caused by neglecting to replace filters, or by changing stream conditions outside the limits set initially. If a new plant is being installed, try to build cleanliness, and the measures to maintain it, into the whole process philosophy. This may involve locating filters at the main plant inlet streams. Alternatively, make sure there is provision for removing the individual filters on each heat exchanger for cleaning. Use self-cleaning filters if possible.

Fluid Velocity

Fluid velocity has an effect on fouling. Any reduction in velocity associated with a lower throughput may increase fouling and necessitate more frequent heat exchanger cleaning. Take this into account when considering the operational flexibility necessary for the process.

Modular Design

Wherever possible, adopt a modular design that uses relatively small heat exchangers. These units can be individually removed for cleaning without total process shutdown. Installing multiple heat exchangers will have economic implications to be considered during design and specification including additional piping complexity.

Cleaning

Where a compact heat exchanger cannot be disassembled for mechanical cleaning (e.g. welded, brazed or diffusion bonded heat exchanger cores), install filtration equipment upstream. Another alternative is to consider chemical cleaning, possibly using a separate cleaning loop.

If chemical cleaning is to be used, ensure that:

- The system is designed to allow the introduction and complete removal of the cleaning fluids used (no dead-legs).
- The cleaning fluids are compatible with the compact heat exchanger and associated pipework over the full temperature range.

In extreme circumstances small exchangers can be baked in an oven enabling the burnt fouling to be removed by rinsing with water or a detergent. Baking to remove serious fouling is unusual, as heating temporarily to such high temperatures will damage most heat exchangers.

Hydraulic Measures

Pulsating flows, reversing the fluids, or stopping the cold fluid intermittently can inhibit some types of fouling, but expert advice should be taken before adopting such techniques, as they can make some fouling problems worse. Air rumbling, i.e. the temporary addition of air or of nitrogen to the liquid stream is frequently used to dislocate particulate or biological deposits.

Cleaning-in-Place Plants

Automatic cleaning-in-place (CIP) plants can be linked to a process plant for cleaning pipes, tanks and heat exchangers internally. Figure 3.2.6 shows the layout of a typical CIP plant.

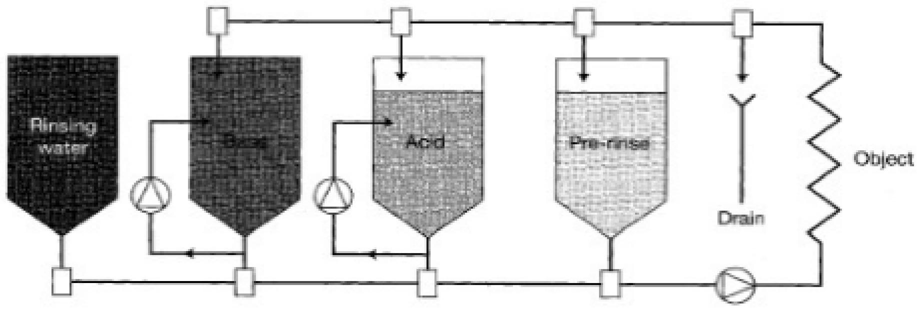

Figure.6 - Layout of a Typical CIP Plant

A typical CIP procedure takes place in five stages:

- A pre-rinse with cold water, helping to displace the product in the system.
- A rinse in an alkaline solution at approximately 80°C.
- A rinse in cold water.
- A rinse in acid solution at approximately 70°C.
- A rinse in cold water.

The cleaning time required depends on the equipment being cleaned and the fluids and temperatures used: it varies from thirty minutes for tanks to five hours for evaporators. In some cases, cleaning time may be reduced by introducing a short acid rinse prior to the alkaline cleaning, thereby helping to remove possible mineral deposits. Single-pack chemicals are also available that remove protein and mineral deposits at the same time.

CIP may be used for removing many types of fouling, including biological slime, rust, scale and organic matter. An example of the efficiency of CIP in removing cooling water deposits is shown in Figure.2. In this example, biological fouling from Rhine river water was removed by a slowly circulating alkaline solution at 60°C[3].

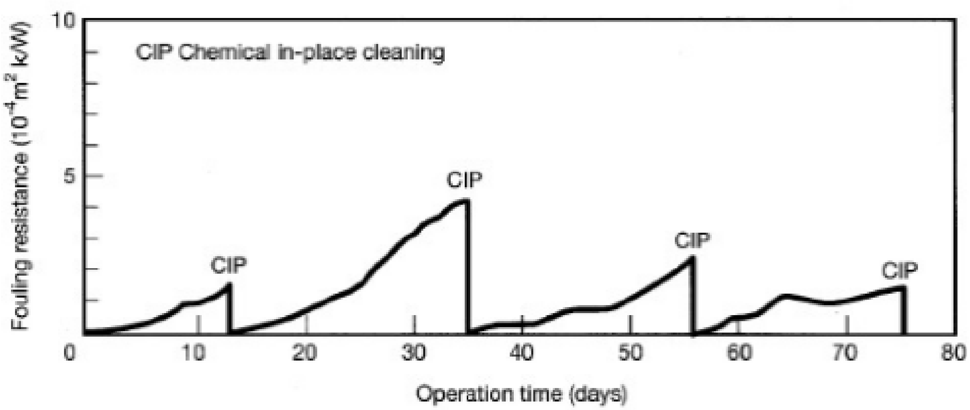

Figure.7 - Reduction of Fouling Resistance by CIP (after Novak)

Typically spent CIP solutions must be treated before release to the environment or recovered for reuse.

4.2 Installation

If fouling is likely to reduce the run time of a compact heat exchanger, consider installing two identical units in parallel. If one becomes fouled, the flow can be diverted through the other. The principle is the same as incorporating a bypass on a waste heat recovery unit to permit cleaning or to avoid plant shutdown in the event of a failure. Take extra care when installing, hydraulically testing and commissioning to avoid fouling and possibly corrosion.

4.3 Operation and Maintenance

Effective operational experience includes the following.

Check Design Limitations

Be aware of the design limitations of the selected compact heat exchangers. A tight design can limit operational flexibility, and optimum performance and minimum fouling will only be achieved when the unit is operated at, or near, its design conditions. For instance any reduction in the velocity of a cooling water stream may increase fouling.

Adequate Training

Make sure that all staff are fully trained in compact heat exchanger operation. Failures have occurred where non-specialists in heat exchangers were unaware of operating practices and experience.

Routine Preventive Maintenance

Compact heat exchangers are more vulnerable to the effects of fouling or blockage than conventional shell and tube heat exchangers. Therefore, give the same high priority to the relevant preventive measures - filters, chemical dosing etc. - as to ensuring that equipment, such as the main pumps, remains serviceable.

Failure or Blockage Procedures

Establish clear procedures for failure situations. When a failure occurs during operation, the general rule is to contact the manufacturer as soon as possible. Mechanical failure during operation may occur because liquids freeze or because of over pressurisation, explosion, damage etc. If any of these occur, contact the manufacturer to discuss the possibilities of repair.

Decide on contingency plans for dealing with a blocked compact heat exchanger, such as cleaning in situ, blocking off the affected layers of a plate-fin heat exchanger, or switching to standby/replacement units.

The mechanical failure of one or more layers in a plate-fin heat exchanger or similar type of compact design need not involve complete replacement. Layers may be blanked off to allow continued operation. In some designs up to 10% of the layers may be blanked off. However, you should consult your equipment supplier before proceeding in this way.

Overhaul Procedures

Establish clear maintenance and overhaul procedures. Some compact heat exchangers can be sent off-site to be overhauled. This is particularly beneficial in the case of gasketed plate heat exchangers, as the gaskets are refitted to manufacturers' standards. If heat exchangers with gaskets are reassembled on site, ensure uniform gasket compression to minimise the risk of leaks. Use gaskets supplied by the heat exchanger manufacturer. With all reassembly, it is important to ensure that the manufacturer's recommendations are followed.

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