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APPLICATION OF ULTRASONIC PROCESS IN MEASURING FLOW OF EXHAUST GASES IN BS6 ENGINES-STATE OF ART REVIEW

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Abstract: While monitoring a process related to instrumentation and control application in different fields of science and technology the measurement of flow becomes necessary. This paper aims to review the current potent technologies of ultrasonic flow meter that can be used in the measurement of the volume of exhaust gasses from BS VI engines. By proper measurement and monitoring of the amount of gas exhausted from the engine, it can be properly maintained and emission of gasses like CO_2 and other CFC can be controlled. The different types of ultrasonic flow meters are used in different fields and also automobile industries in monitoring of fuel consumption. This study aims to review and validate its use in monitoring of exhaust gases in BS VI engines.

Index Terms **- Ultrasonic flow meter, transmit-time flow meter, Doppler flow meter, non-contact type flow meter, BS VI engines, exhaust gases monitoring.**

I. INTRODUCTION

BS VI is a new emission standard that all new vehicles in India are supposed to follow from 1st April 2020 onwards. Thus the new vehicles in the country will be equipped with BS VI engines therefore proper monitoring of emission from this engine will be needed to meet the guidelines of emission norms.

BS VI engines are being developed to meet the challenge of the emission norms arrived out of in hand situation of increased level of pollution pan globe. BS VI engines are equivalent to the Euro VI engines. Situation demands such a rigorous and prompt development of this generation of engines that in India, development of engines equivalent to Euro V has been omitted and automobiles are migrating directly from BS IV types to BS VI. This is majorly because of delays that have occurred in due migration of engines from BS III to BS IV. The chronological requirement of this migration is shown in figure 1. As evident from the figure that by 2020 timeline for using BS V engines in India is over, but still by the end of this time, the use of BS IV engines was popular in India. Thus to match steps with the international genre of engines it was decided to have a leap from BS IV to BS VI, skipping BS V engines. [1]

Different competitive strategies for adopting the technology for improving the emission control are being followed by the manufacturers. Recirculating the exhaust gases through EGR, managing the air fuel for cold start on fuel injection, use of three ways catalyst converters etc. has been proposed. [1]

In a feature article by Masanobu Akita and Tim Nevius on Development of a High Temperature Exhaust Flow meter for Diesel Emission Measurements, need on measuring the exhaust volume of engines for determining emissions of engine mass has been reported.[2] Use of ultrasonic exhaust meters has been reported in the article, but has been criticized due to limited temperature application. Development and application of high temperature ultrasonic flowmeter for measuring the engine exhaust volume has been advocated in the study.[2]

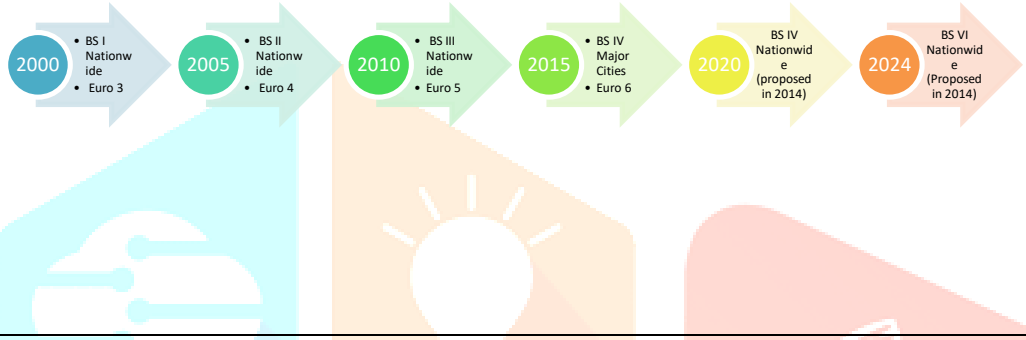

Figure 1: Timeline for migration of different generation of engines

The flow meters have been used in many fields in different devices and can also be used in BS VI engines to monitor the volume of exhaust gasses releasing from the engine. To explain these technologies literatures have been reviewed and presented in this study and also a block diagram to explain the placement of flow meters in BS VI engines is proposed in the methodology. The technology of ultrasonic sensors and its types have been detailed hereunder.

Ultrasonic Flow Meters

An ultrasonic flow meter as shown in figure 2 is used to calculate the value of discharge. The ultrasonic flow meter uses sound waves in monitoring the fluid flow rate. When the fluid is studied the frequency the transmitted and receiver waves is almost the same and when fluid is flowing the frequency of received waves is different because of the Doppler Effect. When the fluid travels quickly, the frequency shift grows linearly. The transmitter routes the signals from the reflection and the transmitted wave. This helps in deciding the flow rate.[3]

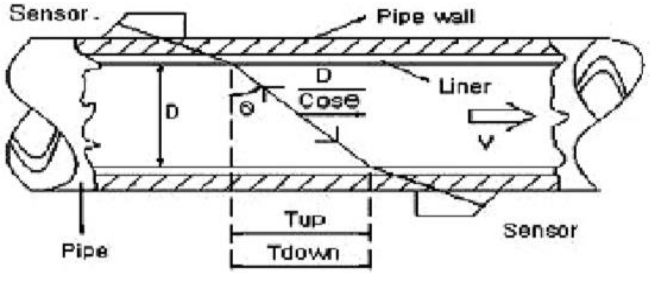

Figure 2: Ultrasonic flow meter[3]

The ultrasonic flow meters can be affected by the acoustic properties and also by the properties like temperature, density, viscosity, and suspended particles or debris in the fluid. Such flow meters don't have any moving parts, and are not affected by silt, suspended solids, chemicals, or grease in the flow stream thus have less maintenance cost and are inexpensive to operate.

The performance of the meters may be ruined by, false echoes from obstructions, solar heating of the sensor, steam, turbulence, foam or strong wind. These problems can be solved by the methods such as use of sensor sunshades for solar heating, proprietary control schemes to adjust amplifier gain for increasing the echo strength, angling the sensor face to reduce the built up steam condensate, variable blanking distances for eliminating the early / late echo returns) and application of dampening factors to reduce the peaks.

Ultrasonic sensors are not advised for use in less than 6 inch wide cross-section (due to possible beam spread) or where steam, foam, turbulence, floating debris / oil / grease are present. A temperature sensor is also attached either integral or stand on in order to compensate the effect of temperature in velocity measurement.

Types of Ultrasonic Flow meters

Different types of ultrasonic flow meter depending upon process of findings velocity are:

1. Doppler type ultrasonic flow meter

Doppler Ultrasonic Flow meters also called as Ultrasonic Doppler Flow meter measures the flow of liquids containing suspended particles or aerated liquids. Suspended pericles reflect some ultrasonic waves which collide with the particle. The Doppler flow meter transmits ultrasonic waves into the liquid and records the frequency shift. The flow meter's clamp-on design allows quick and low-cost installation and eliminates problems related of fluid compatibility and pressure head loss. Having almost no moving parts, there is no mechanical wear, so repairing cost is minimized.

2. The transit-time type ultrasonic flow meter

In a transit time type ultrasonic flow meter shown in figure 3 there are two transducers mounted outside the pipe angled at each other. Whenever a pulse is released by the upper transducer the lower transducer detects it and the transit time for the downstream flow is detected. Similarly when a pulse is released by lower transducer it is detected by the upper transducer and it gives transit for upstream flow.[4]. Pulse transit time in downward direction can be expressed as shown in equation 1.

$$td = L /(c + v\cos \phi) \quad (1)$$

Where,

- td= pulse transmission time in downward direction
- L = distance between transceivers
- V = velocity of fluid flow
- c = fluid velocity of sound similarly,

The pulse transmit time in upstream direction can be expressed as shown in equation-2

$$tu = L / (c – v \cos \phi) \quad (2)$$

Where,

- tu = pulse transmission time in upstream direction

As the sound travels faster in downward direction than in upward, the transmit-time difference can be expressed as shown in equation 3 and 4.

$$t = td –tu \quad (3)$$

$$t = 2vL\cos \phi / (c^2-v^2\cos^2 \phi) \quad (4)$$

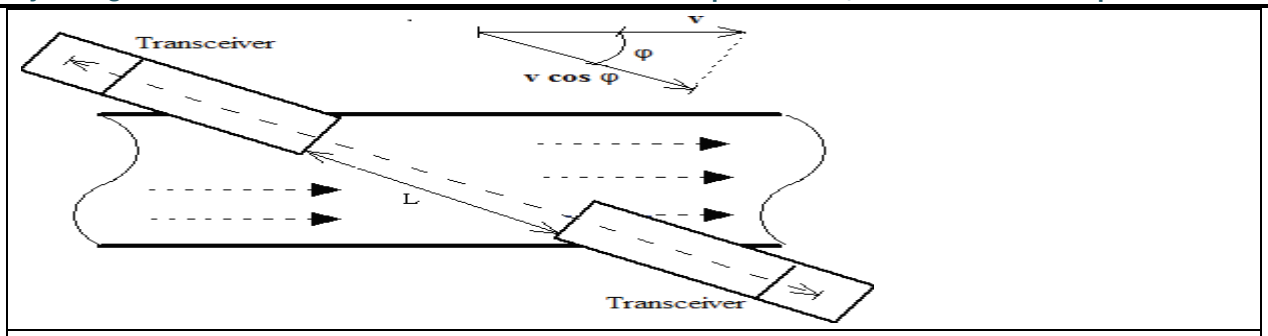

Figure 3. Transit type ultrasonic flow meter[4]

Since v << c,

Using equation 3 and 4-

$t = 2vL\cos\phi / c^2$ (5)

Equations 1,2,3,4 and 5 represent the velocity characteristic in transit-time ultrasonic flow

II. LITERATURE REVIEW

1. The study performed by Ling Ma Jia Liu, Junzheng Wong in (2012) was related to the estimation of differential time of flight. Regarding this the new method of spline-based algorithm was used that can solve this problem because its calculation accuracy is also higher than other methods but the calculation algorithm is huge. For counting the huge calculation problem an improved spline- based algorithm is proposed and in addition to that placement of the sensor is also discussed in the paper. Keeping all these problems a study is performed and following results are obtained:

By improving the spline-based method the running time can be successfully reduced and its stability is better than the cross-correlation algorithm.

a. The mounting position of the transducer highly affects the accuracy of results.

It was observed that for increasing the accuracy fluid sensor placement should be made adjustable. This facilitates re arrangement of sensor in the future as it is required according to the flow of liquid.[5]

2. In the study performed by P.Siriparinyaan, et al, in 2017 effect of the installation of ultrasonic flowmeter on the velocity measurement in a pipe was discussed. The experiments were performed especially at angles 45^0, 55^0,65^0,75^0 and 85^0 by wing-CFD techniques, wing realizable K-E model, and measured by transmit-time ultrasonic flow meters. The result obtained were-

a. As the path angle away from recommended specification was set then more errors in the velocity was observed

b. The velocity at 65 and 85 were almost same because of the path angle from the ones that estimate velocities are lower than the actual ones, especially at small installation angles.

As per the installation of sensors at different angles the installation must be adjustable because flow would be for different fluids and future conditions which can be changed after and the calculation should be precise enough in terms of reaching true value.[6]

3. In the study performed by Chul-Ho Lee et al, in 2017, a new method (TOF)-type ultrasonic water meter is introduced

for smaller flows diameter flows because mainly the ultrasonic flow meters are designed and set for flow meters greater than 6 inches, unlike the exiting TOF method. A new differential TOF algorithm is proposed to calculate the flow rate irrespective of the water temperature. Authors have also focused on low-power design by minimizing the computer position of the micro-controller. Experiments are performed regarding this and the result of experiments are unlike

a. The exiting TOF technology algorithm calculates the flow rate irrespective of water temperature and it is expected that it can be used to measure the flow rate of rivers, water channels, in the future.

In terms of making the velocity measurement uninterrupted by temperature, the sensors should be shaded from poor conductors of heat objects so that the effect of heat can be minimized from the outside environment. [7]

4. In the study performed by Ria Sood, et al. in 2013 development of an automatic water flowmeter is proposed. As it is known that different crops need different quantities of water which is predefined, so by feeding the required data in the automatic flowmeter water can be controlled and saved from being wasted in the field. Their meters can be placed on channels of water entering. For this G1/2 Hall effect, the water flow sensor is used as a sensing unit with a turbine rotor inside it a speed of rotation changes with the different rate of flow of water. The result of this study is

a. An automatic water flowmeter can reduce or save water from being wasted

b. Automatic operation or self-monitoring of water can be easily done and the method proves cheaper than other available systems in the market.

In terms of automating the flowmeter a system that has a flowmeter at the main channel from where the water enters the fields was designed and by the coordination of these two a better automatic flowmeter can be developed.[8]

5. In the study performed by S.S.Walwekar et al, authors propose a technique for measurement of liquid flow using ultrasonic flowmeter (UFM) AS10NIC 400W. This device is capable of measuring velocity in a sealed pipeline fitted by the transducer. The flowmeter is static and is an integral and hermetically closed static water meter for the registration of both cold and hot water consumption. For these ideas, a study is done by the authors and the outcomes of the study are :

a. The system enables the saving and proper use of water the system can be used in many applications and different fields in the future.

b. In terms of making the flowmeter automatic, we have to design a system which not only has the flow meters on the channel of an individual field but allow have a flowmeter at the main channel from where the water enters to the fields and by the combination of two we can make a better automatic flow meter.[3]

6. In the study performed by Jason T. Rizk, et al, in 2016 design of ultrasonic instrumentation for non -circular geometric pipes is done, such as, designing ultrasonic flow meters for the primary coolant flow rate in an integral modular nuclear reactor. Regarding this problem experiments are performed and the results of the experiments are:

AThe ultrasonic insemination can be used to measure flow rate in channels with non -circular cross- section

b.The error between the turbine flowmeter and ultrasonic flowmeter is nearly 8%, 5% of this error.

Here the flow meters are tested for rectangular cross-section but there is another cross- section of pipes too so a universal system could be developed which may be compatible for flow in all types of the cross- section.[9]

7. In the study performed by K.V.Santosh in 2015 a technique for measurement of liquid flow velocity using both the ventury and ultrasonic flowmeters is proposed. The main objective of this study was to improve the sensitivity and linearity of the venture flow meter, to design a multi-sensor data fusion (MSDF) architecture for using an ultrasonic flowmeter and lastly the detection and diagnosis of faults in sensor if any. The Fuzzy logic algorithm is used for fused outputs of both sensors in terms of sensitivity and linearity. The results of the study are:

a. Improved linearity and sensitivity characteristics as compared to instruments with a single sensor is observed

b. The percentage of error is also less so that it can be implemented in industries.

Using both techniques is new and also second to be successful from the results. And making the system more precise and more accurate will help in getting accurate values of flow measurements.[10]

8. In the study performed by David Lozano and Luciano Mateos in 2008 a study of irrigation of land in Spain and other

countries is done by using ultrasonic flowmeter (Risonic 2000 and Argonaut -SW) for an entire irrigation season. The instruments were installed in a rectangular cross-section of one of the secondary canals in the B- All irrigation scheme, Spain. For the entire season, these two devices were tested and the outcomes of the study are

a. Both Risonic 2000 and Doppler - tire (Argonaut -SW) flow meters provides a good result, they are capable of installing in cannel in fields, the Risonic 2000 which is mounted on cannel walls works uninterrupted for the entire year

b. The Argonaut – SW which is mounted at the bottom of cannel got interrupted by the debris flowing there.

The measurement of flow in rectangular cross-section is done by using a combination of two sensors in which the sensor which strives mounted on the bottom of the channel gets affected by the debris flowing there and this will lead to a huge change in the results. So, the lower sensor at the bottom can be protected by making a cover against it from four sides which may protect it at least up to some extent.[11]

9. In the study performed by Sanehiro Wada, et al in 2012, a new method is determined for the optimizing the number of transducers using an ultrasonic velocity profile (UVP) for accurate flow rate measurement. A UVP is also proposed to find an accurate flow rate using multiple transducers under non-developed flow conditions formed downstream of an elbow. The new estimation method employs FFT (Fast Fourier Transform). Results obtained were:

a. A new method to accurately determine the optimal number of transducers using flow rate downstream of the elbow is developed

b. The flow rate errors converge at the number of transducers which was estimated using the wave number and sampling theorem.

A new method for measurement of the ultrasonic velocity profile is introduced here and the results also seemed to be satisfactory. In addition to that the system can be made more accurate by proper placement of the sensors and keeping the full information of fluid to be tested.[12]2

10. In the study performed by Kenichi Tezuku, et al, in the year 2002, the use of clamp- on type ultrasonic pulse-Doppler flow meters is considered to be suitable for the flow profiles which are dependents on the Reynolds number and surface roughness. For this situation clamp-on type ultrasonic pulse-Doppler flow for flow measurement in large steel pen stock are proposed to be used. Using this system some observations are taken by the authors and the results of observations are

a. The data received by the observations of two- line measurements were satisfactory and using this method at the power station provides highly accurate flow measurement.

b. In hydraulic power stations the amount of feed water is very important as it decides the speed of the turbine.

Hereby using clamp-on type ultrasonic pulse-Doppler flow meters can improve the system accuracy. To increase the accuracy here more than one type of flowmeter can be used.[13]

11. In the study performed by Ling Guo , et al, in 2014, authors have shown a new method of measurement of the velocity of a fluid. This ultrasonic flowmeter is better than a conventional flowmeter performance since it has no pressure loss, no moving parts, and it is widely used in industrial production. This type of flowmeter comprised of an ultrasonic transducer installed on the measuring pipe. In this paper the flow field of ultrasonic flowmeter was examined with small diameter that measures the velocity of a fluid with ultrasound to calculate volume flow. This paper reviews the unique capabilities of transit-time ultrasonic flow measurement technology and explains how recent advances have allowed this technology to be used in various technology.[14]

12. In the study performed by Deok-woo Park, et al, in 2017, it was quoted that ultrasonic flowmeter is a device that finds the velocity of a fluid with ultrasound to measure volume flow rate. In this technology the velocity of flowing fluid can be measures along the path of an emitted beam of ultrasound with the help of a transducer. In this technology two transducers are mounted on the outside of the pipe. For a transit time, ultrasonic flowmeter both transducers serve alternately as transmitter and receiver of ultrasonic waves. Ultrasonic flowmeter provides the capability of measuring water accurately.[15]

13. In the study performed by Bahareh Tavousi Tabatabaei, in 2019, author has shown a new technology of measuring the velocity of flowing fluid with the use of ultrasonic speedometer to calculate volume flow. An ultrasonic flowmeter is a device that measures the velocity of flowing fluid without having contact with the flow, which causes no pressure drop. The advantages of this technology include low maintenance cost, low-pressure drop-in-measurement, and high accuracy. The ultrasonic speedometer has no side effect on the pressure of flow because it has no contact with it. This technology provides the accurate velocity of flowing fluid without having contact with the flow. [16]

14. In the study performed by Vikas Kumar Vidyarthi, et al, in 2017, authors discussed a new method of measuring a velocity of flowing fluid. It applies to a transit-time ultrasonic flowmeter device. It measures the difference in time from when an ultrasonic signal is transmitted from the first transducer until it crosses the pipe and is received by the second transducer. If there is no flow the travel time will be the same in both directions. This paper gives a short review of the advancement in various aspects of ultrasonic transit-time flow meters for pipes. The velocity rate of the flowing fluid can be determined by an ultrasonic flowmeter with the help of a transducer.[17]

15. K. Barsaukas in the study done in 2015 author measured the liquids with a specially designed ultrasonic laser interior meter and pulse-echo system. This review paper is a survey of the further investigations in the field of ultrasound velocity measurements. Author has proposed the model to estimate the hydration number of the electrolyte solution of the molar compressibility using the ultrasonic laser meter. According to this theory the main experiment was provided in the synovial and cerebrospinal fluid to improve disease diagnostic.[10]

16. K. A. K. Rajkumar, et al, in their study done in 2018 research about theoretical velocity of the binary liquid mixture of ethyl lactated with 2-propanol, 2- butenol, and 2-methyl propane was conducted. The results of the paper are subjected to discussion in terms of intermolecular interaction between the components molecules in the binary liquid mixture. This theory is used in the laboratory or chemical industry to measurements of the ultrasonic velocity of the chemical flow.[18]

17. S. Nithiyanantham in thier study done in 2017 solved the problem of measurements of the liquid flow. In present time measurements of the ultrasonic investigation are found, expensive applications and data in the investigation are found and also judge the behavior of the liquid mixture. In this paper further concepts are used with imperial formula like Li=K/Uexp*P^(1/2)exp Where Li= free length Uexp= experimental ultrasonic velocity. This theory is under in top 10 theory models of ultrasonic velocity for the fluid mixture. This is a more accurate theory thus a good opportunity to use this theory in measurements of ultrasonic velocity of the fluid mixture exist.[19]

18. Venkateswara Rao in 2018 gave a new theory the the experimental value of ultrasonic velocity is different as compared to the calculated value for binary mixtures was proposed. In this theory author developed a table which observed that the Nomato's theory exhibits more satisfactory results for all the four systems. In this theory, to obtain maximum accuracy a temperature sensor [either integral to the ultrasonic sensor (preferred) or as a stand-alone sensor] is required to compensate for changes in air temperature.[20]

19. In this paper published in 2019 the author, Nithiyanantham , used twelve theoretical models of ultrasonic velocity for the various liquid mixture. This theory was valid with experimentation. Further it is stated that all the methods used in this theory for investigation, successfully agree with the experimental value. The transit time corresponds to the distance between the face of the sensor and the surface of the water that is taken in the theory. The above theory is useful for future applications. A general equation is fit to explain the liquid property and accurately.[21]

20. In the study performed by L. Svilanis, et al in 2010 for transport control and analysis, an ultrasonic flowmeter is used to monitor the diesel consumption rate in the engine. The initial study was focused on the feasibility of design using the time of flight type ultrasonic flow meter. Numerical experiments for the prototype is carried out using signal energy, operation frequency, and bandwidth, electronics noise, analog to digital converter, sampling speed were taken into account. For these parameters, numerical experiments are performed and the result of the experiments is –

a. Under zero flow condition the transit time difference has 2,4ps standard deviation, and - 0,29ps average and virtual flow have 0.00004 m/s standard deviation and 0.000005 m/s mean.

This study confronts that ultrasonic transit time flow meter with parameters used for the initial study is feasible. As the above study focused on the monitoring of fuel consumption using the parameters like coolant flow to the engine or exhaust of harmful gasses can be monitored using an ultrasonic flow meter and can be controlled.[22]

III. METHODOLOGY

The BS VI engine based on diesel fuel, emits higher PM and NOx than petrol. For NOx reduction, all diesel engine have above two liter. In which a selective catalytic reductions (SCR) are used which is a clever emission system that injects ammonia based urea into the exhaust and triggers a chemical reaction that essentially converts NOx into non harmful nitrogen add water. This technology can achieve NOx reduction up to 90% and allows diesel engine to comfortably meet the norms.

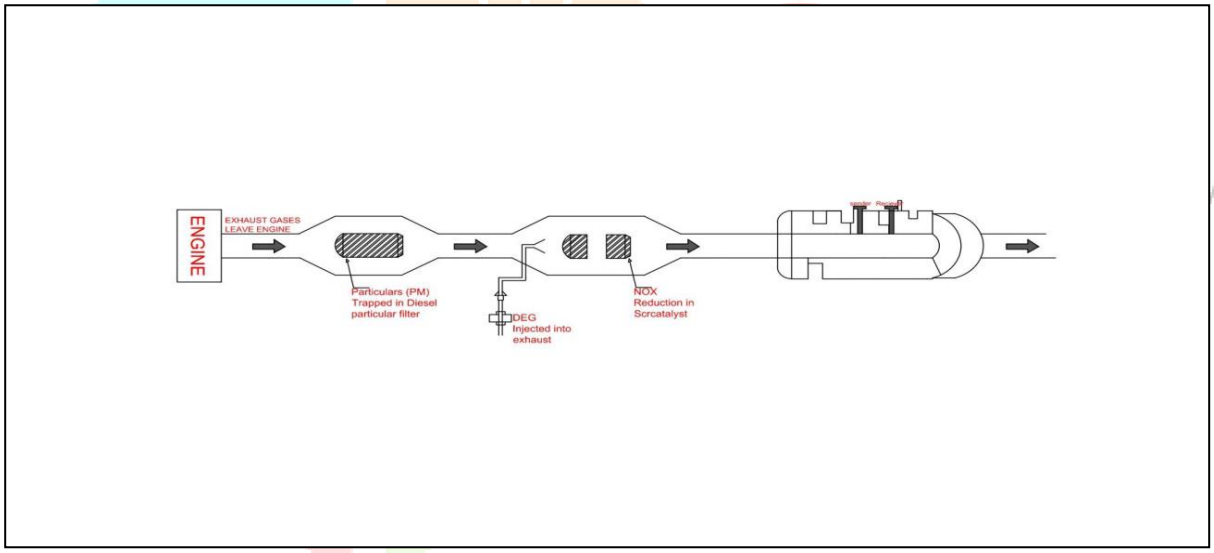

Figure 4: Proposed placement of ultrasonic flow meter on exhaust system in BS VI engine

In this process the canister is placed at downstream of the engine exhaust manifold NOx as the name suggest. When the canister is filling up, a richer fuel mixture is injected into the engine and that reacts with NOx and converts into harmless nitrogen, and is then expelled from the LNT into the exhaust system.

A fluid flow meter is also used at this end of the exhaust system. The fluid flowmeter is based on the Doppler Effect. In this flowmeter a sensor is used that sends signal, which collides with different particle molecule and also receiver can receive the signal after the collision. By this process it is possible to measure the actual distance between particle molecules, as this type can also calculate the velocity of fluid that are flowing in the exhaust system. By this process measurement of actual amount of fluid in the form of discharge that can emit into the environment are possible.

The proposed placement of the is shown in figure 4.

IV. RESULTS AND DISCUSSION

The literature studied has shown the importance of ultrasonic flow meter in BS6 engines. The ultrasonic flow meter can help in monitoring the flow of exhaust gasses and controlling them. The review also shows the parameters the affect accuracy and performance of ultrasonic flow meters. A review of this work also shows that in the future with improvement in new technique like(TOF) type ultrasonic flow meter, clamp-on type ultrasonic flow meter, and pulse-Doppler ultrasonic flow meter the accuracy and performance of ultrasonic floe meter in BS6 engine can be also be improved.

V. ACKNOWLEDGMENT

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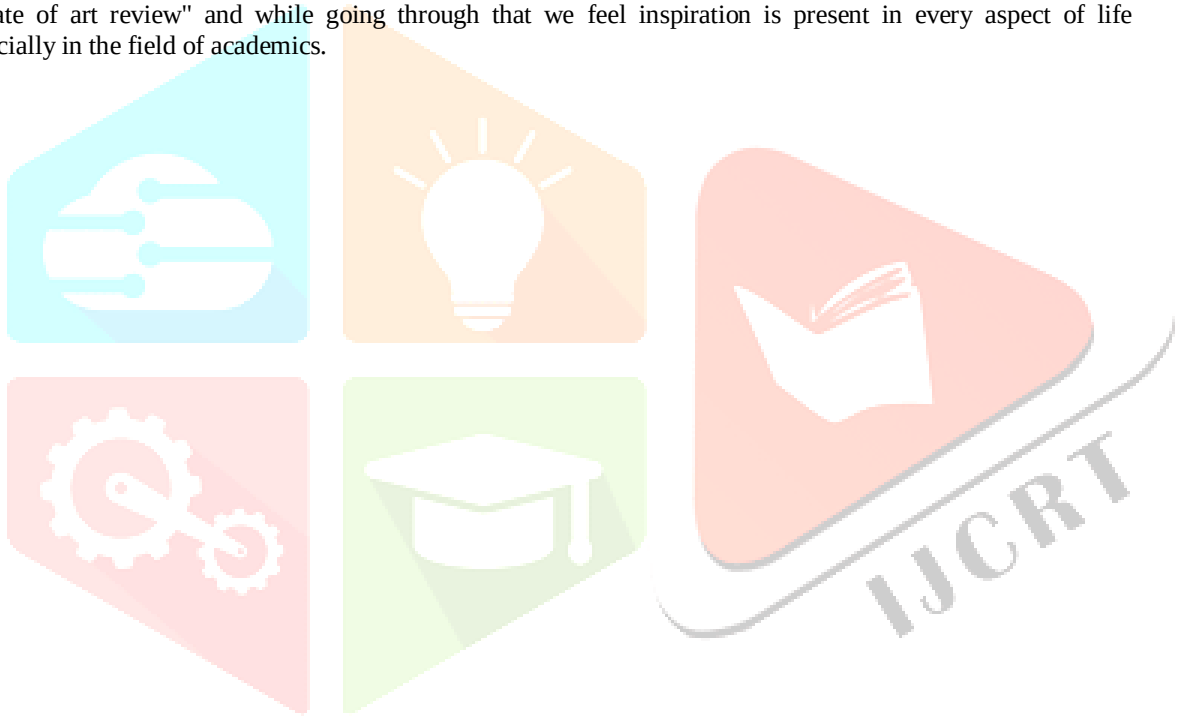

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