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Experimental Investigation into Chaotic Features of Flow Gauges in Automobile Fuel Metering System

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***Abstract*—**Chaotic system may lead to instability, extreme sensitivity and performance reduction in control systems. It is therefore important to understand the causes of such undesirable characteristics in control system especially in the automobile fuel gauges. This is because without accurate fuel gauges in automobile systems, it will be difficult if not impossible to embark on a journey whether during odd hours of the day or where fuel is difficult to obtain. To this end, this work studied the impacts of fuel tank rust and faulty component of fuel gauge system (voltage stabilizer) on the chaotic characteristics of fuel gauges. The results obtained were analyzed using Graph iSOFT package. Over the range of experiments conducted, the results obtained showed that rust effect of the fuel tank would alter the flow density, consequently the fluid pressure and ultimately the flow velocity of the fuel. The responses of the fuel gauge pointer to the faulty voltage stabilizer were erratic causing noticeable instability of gauge measurands indicated. The experiment also showed that the fuel gauge performed optimally by indicating the highest degree of accuracy when combined the effect of rust free tank and non-faulty voltage stabilizer conditions (± 6.75% measurand error) as compared to only the rust free tank situation (± 15% measurand error) and only the non-faulty voltage stabilizer condition (± 40% measurand error). The study concludes that both the fuel tank rust and the faulty voltage stabilizer gauge component have a significant effect on the sensitivity of fuel gauge and its accuracy ultimately. Also, by the reason of literature, our findings can also be said to be valid for all other fluid meters and gauges applicable in plant machineries and most hydraulic systems.

***Keywords*—**Chaotic system, degree of accuracy, measurand, sensitivity of fuel gauge.

I. Introduction

CHAOS refers to random and unpredictable phenomenon or the behavior of a complex system, where tiny changes in the starting conditions leads to very large changes over time. The accepted definition of the term accuracy in measurement of any kind is based on the ratio of the indicated measurement to the true measurement [1]. For flow measurement the ratio is indicated flow to true flow, this seems to be a rather simple problem until an attempt was made to define and demonstrate true flow. However, there has been extensive research in this area and a number of terms exist which can be used to determine the uncertainty in the accuracy of flow meters [2], [3]. In recent publications [14], a flow meter was defined as a device that meters movement of fluid in a conduit or an open space. This fluid could be water, chemicals, air, gas, or steam. These abnormalities in the flow meters have been described by many different words which depend on how well a meter will perform in measurement. These include: accuracy, uncertainty, error (systematic and bias), repeatability, hysteresis and reproducibility [10]. Without getting into a detailed lesson in statistics, the term uncertainty is defined as the statement of test data to a limit of which 95% of the data taken will fall [4]. Flow meter uncertainty was defined as two standard deviations of the data [12]. At times, arriving at the proper magnitude of the error involved is the hardest part of the calculation of uncertainty. According to [5], [6], [11] and [13], there are three general categories of fluid meters installation uncertainties: (i) The mass (volume at base conditions has a related value to mass) flow condition; (ii) Physical properties of the fluid; and (iii) Imprecision of installation parameters such as orifice diameter and ageing design materials. For flow meter use, the adaptation to relevant process conditions can be achieved by characterizing the meter over the whole range of flow rate, temperature and, in certain cases, pressure. On the other hand, [8] and [9] state that "a meter should always be calibrated in the fluids in which it is to be used", as there are significant effects on the meter characteristic due to viscosity and density variations. In further works which attempt to reduce the chaos caused by uncertainties in flow meters on newer vehicles, the on-board diagnostic system (OBD II) is required to monitor the fuel system for vapor leaks. If the fuel in the tank gets too hot and builds up excessive pressure, it may cause a leak that will show on the Malfunction Indicator Lamp (MIL) and set a diagnostic trouble code (DTC) [11]. This reduces the risk of excessive pressure build up inside the fuel tank, vapor leaks, and triggering an OBD II. Fig. 1 shows a return-less flow systems in automobile fuel metering system.

Energy extraction is recognizable as a pressure drop across flow meter. Thus, it is obvious that the meter characteristic and its parametric dependence from the respective fluid properties such as density, viscosity, fluid temperature and pressure, is not simply determined in a way, which is defined by the fluid flow [7], but additionally by the flow sensing element inserted in such an ideal pipe flow. This additional meter component causes a more or less tremendous disturbance of the pipe flow profile, and, thus, it affects the meter characteristics. The uncertainty of a vortex flow meter was evaluated by [12] based on a novel mathematical measurement model and airflow experimental results. The experiments were conducted in a 50-mm-diameter pipe with the Reynolds numbers from 9.42×10^3 to 8.48×10^4, and vortex frequencies were calculated by spectrum analysis of the

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differential pressures obtained on the pipe wall. Increased attention had focused on the reasons for the uncertainties in the accuracy of fluid gauges and flow meters. Since the 1990s, both laboratory and field studies showed that the physical, chemical and the environmental factors could have a notable impact on the sensitivity and the accuracy of the meter measured output. Environmental conditions such as ambient temperature, the gauge system component service conditions and electric power fluctuations have significant effect on the flow meter output. The chemical components of the fluid in use in the meter system, the fluid density, the pressure and the flow velocity also lead to poor accuracy of these flow meters and consequently result into their chaotic behavior. Considering the vital role of fuel gauges in automobile system, this work investigated its chaotic characteristics when the fuel tank is rust and voltage stabilizer is faulty.

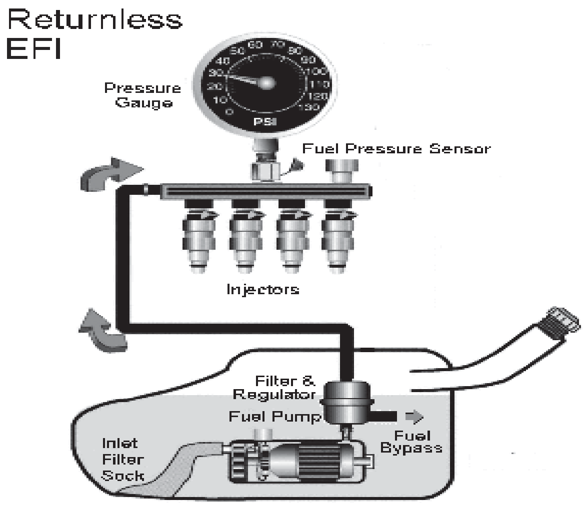

Fig. 1 Return-less flow systems in automobile fuel metering system

II. Materials and Methods

A. Materials

Various diameters of delivery pipes and hoses, large funnels, 50-liter plastic container glued with hose pipe for delivery purpose. Adjustable workshop stand, premium motor spirit (petrol), fine dust of iron filings with average density of 719.7kg/m^3, beam balance, plastic containers, analogue and digital fuel gauges (Fig. 2 shows analogue gauge of benz 200), stop watch and fire extinguisher as safety measure were provided.

B. Method

The experiment was performed with a regular Benz 200 car in a stationary state. In many cases the car is immobilized on jack stands for safety. The staging of the experiments was planned to control the critical components of the car fuel systems and ensure safety. The investigation was performed during the early hours of the day to avoid evaporation of the gasoline since it is highly volatile, thus preventing undue loss in the volume of the fuel used in carrying out the test. This location was chosen because it provides a convenient environment isolated enough for the test. With the assistance of an automobile technician, the delivery pipe in the car connecting the fuel system especially the hose from the sending unit to receiver end was disengaged carefully and fit with a two meter length hose which was tapered into a short hose serving as the delivery end of the plastic tank. The fuel tank of uniform rectangular shape was graduated linearly with meter rule for every difference of 5-litre of gasoline. The improvised fuel tank was placed on the adjustable stand and was set to the height of 63cm from the ground level, measuring to the equivalent height of fuel tank location in the car. Using a large funnel, the tank was filled with 40 liters gasoline. Ensuring no leakage along the joint areas, the fuel tank and the entire set up connected to the vehicle was air and pressure tight. To enhance the control of certain factors like high temperature which may directly affect the result of the experiment, both experimental set up were staged and carried out repeatedly in the morning before the weather gets excessively warm. This prevented undue evaporation of the used process fuel despite the measure taken to make the fuel tank airtight. Also with low ambient temperature in the morning time of the day, there was a little or no chance of inflammability of the gasoline, this ensure safety from unexpected fire explosion.

Fig. 2 The analogue fuel gauge of the regular Benz 200 car being investigated

1. Data Acquisition for the Normal Process Fuel Flow Test

The car was filled with ppms of initial actual volume (Vo) of 45 litres at initial time (T_o) of 0.0 minute with initial fuel pointer on analogue metre indicated P_o = above ¾ full capacity. The experiment was now run by putting on the ignition of the car until when the actual volume of the fuel noted on the graduated mark of the tank decreases by 10 litres in each experimental run. The respective time for each run was taken using stop watch. The actual volume read on the graduated mark during each run, the respective time it takes for each run and the indicated readings on the dashboard analogue and digital metre were taken.

2. Data Acquisition for the Contaminated Process Fluid Test

In order to start with the same initial volume (45 litres) as in the case of normal process fuel flow, the car was filled with ppms of initial actual volume of 40 litres and 150 g of fine dust of iron fillings amounting to total initial volume of 45 litres. The initial time (T_o) on the stop watch was 0.0 minute and fuel pointer reading on the analogue metre indicated P_o = above ¾ full capacity. Subsequently, the experiment was run by putting on the ignition of the car till when the actual volume of the fuel noted on the graduated mark of the tank decreases by 10 litres in each experimental run. The respective time for each run was taken using stop watch. The actual volume read on the graduated mark during each run, the respective time it takes for each run and the indicated readings on the dashboard analogue and digital metre were recorded.

3. Data Recorded with Good Voltage Stabilizer

With voltage stabilizer in good condition, and initial time T_0 = 0.0 minute. Time interval of 25minutes was chosen and experiment was run for each of this time interval. Corresponding volume of ppms as indicated in the dashboard analogue and digital metre were recorded.

4. Data Recorded with Faulty Voltage Stabilizer

With voltage stabilizer in bad condition, and initial time T_0 = 0.0 minute. Time interval of 25minutes was chosen and experiment was run for each of this time interval. Corresponding volume of ppms as indicated in the dashboard analogue and digital metre were recorded.

III. Results and Discussions

A. Data Acquisition for the Normal Process Fuel Flow Test

Table I shows the documentation for normal process fluid test. Where s/n is the number of test conducted for each experimental set up, T_n is the duration of time recorded for each experimental set up for equal successive interval of spent fuel quantity, V_t is the actual volume of the fuel in the fuel tank as progressively noted during the test and V_i is the indicated quantity of fuel on the fuel gauge as progressively noted during the test. As can be seen in the table, as the time for experimental run increases the indicated analogue volume decreases (The implication of the analogue volume indicated is as shown in indicated digital volume recorded). This observation is in line with the expectation as the fuel is expected to decrease with the time engine is put to run.

TABLE I
THE NORMAL PROCESS FLUID TEST

s/n	*T_n (min)*	*V_t (litres)*	*V_I* *ANALOGUE* ***(litres)***	*V_I* *DIGITAL* ***(litres)***
1	0.00	45.00	Above ¾	105.00
2	30.00	35.00	Below ¾	80.00
3	39.00	25.00	Just ½	60.00
4	47.00	15.00	Below ½	52.00
5	58.00	5.00	Above ¼	38.00

B. Data Acquisition for the Contaminated Process Fluid Test

Table II shows the documentation for the contaminated process fluid test. It can be seen in the table that as the time for experimental run increases the indicated analogue volume decreases (The implication of the analogue volume indicated is as shown in the indicated digital volume recorded). Although the observation is consistent with the expectation as the fuel is expected to decrease with the time engine is put to run. However, the third experimental run became chaotic, as even though the indicated analogue volume reads below half (below ½) as in the case of normal process fluid test yet the implication on the indicated digital metre defers as it reads 54.00 litres on the contaminated process fluid test against 60.00 litres on the normal process fluid test.

TABLE II
CONTAMINATED PROCESS FLUID TEST

s/n	*T_n (min)*	*V_t (litres)*	*V_I* *ANALOGUE* ***(litres)***	*V_I* *DIGITAL* ***(litres)***
1	0.00	45.00	Above ¾	105.00
2	30.00	35.00	Below ¾	80.00
3	39.00	25.00	Below ½	54.00
4	47.00	15.00	Below ½	52.00
5	58.00	5.00	Above ¼	38.00

C. Data Recorded with Good Voltage Stabilizer

Table III shows the documentation for good condition voltage stabilizer test. It can be seen in the table that, as the time for experimental run increases the indicated analogue volume decreases (The implication of the analogue volume indicated is as shown in the indicated digital volume recorded). The observation is in line with the expectation as the fuel is expected to decrease with the time engine is put to test.

TABLE III
THE GOOD CONDITION VOLTAGE STABILIZER TEST

s/n	*T_n (min)*	*V_I* *ANALOGUE* ***(litres)***	*V_I* *DIGITAL* ***(litres)***
1	0.00	Full	120.00
2	25.00	Above ¾	90.00
3	50.00	Above ½	72.00
4	75.00	Below ½	48.00
5	100.00	Exactly ¼	30.00

D. Data Recorded with Faulty Voltage Stabilizer

Table IV shows the documentation for the faulty condition voltage stabilizer test. It can be seen in the table that as the time for experimental run increases the indicated analogue volume decreases (The implication of the analogue volume indicated is as shown in the indicated digital volume recorded). Although the observation is consistent with the expectation as the fuel is expected to decrease with the time engine is made to run. However, with effect from the second experimental run to the last (fifth), the observation became chaotic, as even though the indicated analogue volumes read the same as in the case of normal process fluid tests, yet the implication on the indicated digital metre defers as it reads 82.00 litres as against 90.00 litres-good condition voltage stabilizer (for 25 mins run time), 48.00 litres as against 72.00 litres-good condition voltage stabilizer (for 50 mins run time), 72.00 litres as against 48.00 litres-good condition voltage stabilizer (for 75 mins run time) and 0.00 litres as against 30.00 litres-good condition voltage stabilizer (for 100 mins run time).

TABLE IV
THE FAULTY CONDITION VOLTAGE STABILIZER TEST

s/n	*T_n (min)*	*V_I ANALOGUE* **(litres)**	*V_I DIGITAL* **(litres)**
1	0.00	Full	120.00
2	25.00	Below ¾	82.00
3	50.00	Below ½	48.00
4	75.00	Below ½	72.00
5	100.00	Empty	0.00

E. Combined Test Factors in Normal Process Fuel Flow in the Set Up

It should be noted that if minimum uncertainty is desired, the meters must be applied in the most acceptable portion of their range. On the flow meter, the intermediate betas and higher differentials are the best. On fuel meters, the upper end of their range is the best. The use of material selection is an example of this principle. The use of process fluid nature test to demonstrate state of uncertainty in flow meters is shown on Tables I and II in response to observed data calculations. In these calculations the effect of measurand behaviour due to change in density of the process fluid can be seen. The calculations determine the uncertainty in the standard flow rate for the automobile fuel meters. As permitted by literature review of past works, similar calculation can be made for other type meters. The calculation requires the previous variables such as pressure, temperature, the primary element, differential pressure, etc., and the percentage relative uncertainty of these parameters. There is a tendency to under estimate the uncertainties involved in measurement based on uncertainties that were developed in laboratory conditions. Usually, this does not reflect the field operating condition effects for such items as temperature coefficient, static pressure, atmospheric pressure, etc. The use of smart transducers can minimize some of these effects. The assumption made in the analysis of the data resulting from the experiment was that every instrument was working according to its specification. Proper maintenance has kept them properly calibrated and applied for the operating range and ambient conditions, so that their performance complies with its initial uncertainty specification. With these considerations followed, the uncertainty levels are calculated at a 95% confidence level. This requires the input data to be specified at the 95% confidence level. Even with all of the conditions controlled, the calculated numbers are theoretical, but are more realistic if the conditions above are met. Figs. 3 and 4 show the result of high degree of certainty when the normal conditions of both tested cases are combined. In this case, the sensitivity of the flowmeter is stable and encourages increase in the degree of certainty for the set up provided all other conditions of operation are normal.

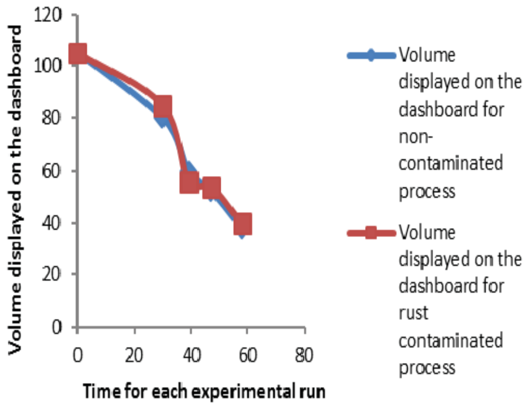

Fig. 3 Plot of volume of ppms displayed on the dash- board against time the vehicle has travelled/ worked when rust component of the tank was being investigated

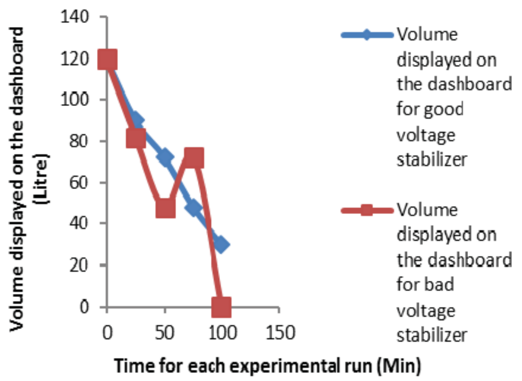

Fig. 4 Plot of volume of ppms displayed on the dash board against time the vehicle has travelled/ worked when voltage stabilizer of the gauge was being investigated

IV. CONCLUSION

This study shows that fuel flow gauges is prone to chaotic behavior when the fuel tank is rust, more prone to the chaotic behavior when the voltage stabilizer is faulty and most prone to the chaotic behavior when the effect of rust fuel tank and faulty voltage stabilizer conditions is combined. The study also reveals that the flow gauges can provide dependable as well as precise measurements in real time for myriad of streams of fluid when carried out in controlled environments.

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