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Design and development of Digital Fuel Economizer

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Research Article

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ABSTRACT

Fuel consumption is the single largest variable cost during field operation of tractors and also one of the most influential parameters controlling the salability of the vehicle, particularly in developing countries. Hence there is a great need for development of a system which can minimize the fuel consumption at any given load for a tractor. The system is required to design by keeping in mind the low education level of farmers of developing countries like India and natural aversion of these farming communities towards complex system during cumbersome field operation. Therefore the prime objective of this paper was to design and develop a simple digital fuel economizer (DFE) system for developing countries like India. Gear-up-throttle-down (GUTD) technique to match the load on tractor during field operation is a popular means to have better fuel economy. The new DFE system was designed to work like a GUTD guidance system. A microcontroller, inductive type proximity sensor and an analog to digital converter have been used to develop the DFE system.

Keywords: tractor, fuel economy, gear, throttle, India, field efficiency

1. INTRODUCTION

Fuel consumption is the single largest variable cost during field operation of tractors and also one of the most influential parameters controlling the salability of the vehicle, particularly in developing countries. It can be argued that tractor is one of the main contributors in total agricultural fuel consumption. For example, nearly 15 to 18% of 40 million tonnes of diesel fuel used per annum in India goes to agricultural sectors and approximately 35-45% of that, is used to run the prime movers like tractor, power-tiller, etc. (Singh and De, 1999). Therefore any means to reduce the fuel consumption of tractor will not only help the farming community but also will be helpful for those developing countries, whose economies mainly depend on agriculture. Rapid socio-economic changes in some developing countries like India, China, etc, are influencing the agricultural mechanization pattern of these countries and expected to do so in future also (Mondal and Basu, 2009). For example, Indian tractor industry is now the largest in the world in number of unit production with an average of more than 0.2 million unit production per year. Total tractor population in India is approximately 2.53 million at present against world tractor population of

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27.63 million. India holds second position in world for total number of tractor in use after USA. Considering the Asia-pacific region, 68.6% of total 7.69 million tractors are placed in developing countries (Anonymous, 2008). Farmers of some states of India are showing the inclination to shift to higher horse power segment without replacing the small capacity implements. This drift of tractor market will worsen the fuel economy condition due to implement-tractor mismatch. Hence there is a great need for development of a system which can act as a guide to the operator to economize the fuel consumption at any given load.

Matching size of implement for tractor is a complex problem during agricultural operation. Only few experienced drivers, who can understand by experience the minimum specific fuel consumption (sfc) zone for particular load and select proper gear accordingly, may achieve better fuel economy. But in general, it can be argued that efficient utilization of tractor power has been always a challenge for farmers, as reported by the researchers though out the world (Ricketts and Weber, 1960; Larsen, 1981; Zoerb and Kushwaha, 1983; Lyne et al., 1984; Grogan et al., 1987; Wang and Zoerb, 1989; Mondal, 2004). A tractor performance monitor system, which will act as a GUTD guidance system, can be helpful to solve this problem. An operator assist system to optimize tractor efficiency has been developed by using the characteristics of engine. The movement of the governor plate in the fuel injection pump has been monitored electronically and the output modified to provide an accurate indication of engine performance. An analogue meter has been provided to indicate the point of best fuel efficiency (Meiring and Rall, 1979). Ground speed and fuel consumption based tractor performance optimizer has been developed, which can present graphical display of cost versus work rate (Mertins and Gohlich, 1981). An efficiency number based tractor performance monitor system has also been developed on the basis of travel speed, fuel consumption rate and draft (Clark, J. H. and Gillespie, 1982). But efficiency number based tractor performance optimizer was not very much ‘user-friendly’. A microprocessor-based gear control system for the heavy-duty automatic transmissions is used in trucks and earth-moving equipment. This intelligent gear control system provided better fuel efficiency, overall performance, reliability, and durability (Harmon and Struthers, 1982). A microcomputer based device has been developed to assist the tractor operator in selecting the appropriate gear and throttle setting for a given task. Three variables (engine speed, engine torque, and transmission output shaft speed) are examined by the microcomputer in order to evaluate the use pattern of the tractor and to select the most appropriate gear and throttle setting (Schrock et al., 1985). An automatic system received driver input on desired forward speed, while automatically sensing tractor load in terms of engine rpm decrease. The system then controlled governor setting and transmission ratio with the objective of delivering the desired forward speed while having the engine operate at high torque levels a maximum proportion of the time in order to achieve high fuel efficiency (Chancellor and Witt, 1986; Chancellor and Witt, 1988). At present there is no ‘user-friendly’ device, suitable for farmers with low education status, which can work as a guidance system for the most suitable gear and throttle position. Additionally, a heavy decision-making load is unlikely to be sustained throughout a long working day, without a consequent loss of performance or concentration (Scarlett, 2001).

Therefore, the system is required to design by keeping in mind the low education level of farmers of developing countries like India and their natural aversion towards complex system during cumbersome field operation. Therefore the prime objective of this paper was to design and develop a simple digital fuel economizer (DFE) system. Such a system will work like a GUTD guidance system.

2. MATERIAL AND METHODS

2.1 ENGINE CHARACTERISTICS MAPPING: Draft predicting equations depend on different parameters like soil condition, implement type, speed of travel. Change of characteristics of power source (here engine) due to continuously varying load and subsequent conversion than predicting the draft can be an alternative to estimate draft indirectly. Engine performance maps are obtained usually from 50 to 250 data points and by the interpolation between these points (Wang and Zoerb, 1989). Wang and Zoerb (1989) developed two methods for determination of optimum working points for diesel engines. One method, called the model-plus-test, includes a fuel consumption model and equal slope theorem applied to engine performance mapping. The second method uses a straight line to the optimum torque-rpm equation approximation. The optimum working curve (OWC) provides the optimum torque-speed relation required for the design of a tractor gear selection indicator (De souja, 1999). To create the database within the microcontroller an extensive Part Load Part Throttle (PLPT) test was conducted in dynamometer laboratory. It was assumed that 5% throttle interval is sufficient to provide a representative engine characteristics map (Mondal, 2004). So the PLPT was designed with 5% throttle interval and starting from 50% throttle to 100% throttle. Particularly so because the tractors are not operated below 50% throttle. Throttle (%) has been calculated by equation 1.

$$\text{Throttle (\%)} = \frac{\text{Indicated rpm} - \text{Low idle rpm}}{\text{Rated rpm-Low idle rpm}} \text{ X } 100 \qquad (1)$$

Specification of the tractor used for the experiment has been given in Table 1.

Table 1 Main specifications of the tractor used for experiment

Aggregate	Specification
Engine make	Simpson
Rated rpm	2250
Rated power, Hp	39.4
Cylinder	Dry Type with Turbo Pre cleaner
Clutch	Dual Clutch (with Random Woven lining)
Transmission	Constant mesh with Smart Shift
Gearbox pattern	8 forward + 2 reverse (High+Low)
Wheel base (mm)	375
Overall length (mm)	1650
Battery	12 V, 36 A

2.2 PRINCIPLE OF DFE: Engine speed (ERPM) has been measured by proximity sensor and this ERPM is first compared with 55% of rated ERPM (RERPM). If ERPM is less then RERPM then 'yellow signal' (increase throttle or go to low gear- high throttle position or opposite of GUTD) glows. From throttle position sensor signal of position of throttle is indicated and accordingly Max. power ERPM (MPERPM), lower factor of safety (LFS) and higher factor of safety (HFS) values are selected by microcontroller.

3. RESULTS AND DISCUSSION

3.1 PLPT RESULT: The PLPT result is available in Fig. 1. Mapping of fuel consumption was done simultaneously which was also shown in Fig. 1. For a particular throttle position load was increased slowly to know how power as well as sfc were changing. Same procedure was followed for all 10 throttle positions. Selection of lower factor of Safety (LFS), higher factor of safety (HFS) has been done on the basis of PLPT. It must be noted the selection of LFS and HFS requires thorough understanding of the behaviour of engine during different segment of PLPT as well as experience of designer. Relations of governing parameters of DFE like Max. Power Engine rpm (MPERPM), LFS, HFS etc. with throttle position have been established by second degree polynomial regression analysis and it has been found that 5% interval PLPT was good enough to provide high degree of prediction of accuracy of intermediate values. Governing equations derived from PLPT experiment were fed to microcontroller to create the platform of digital decision support system for best fuel economy.

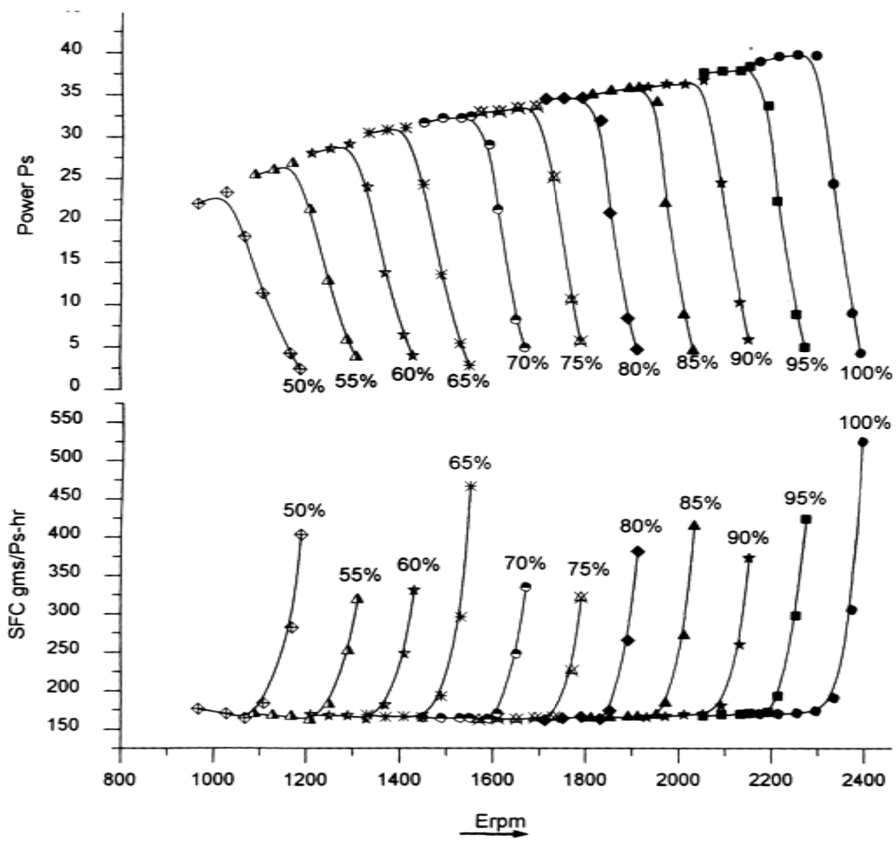

Fig. 1 Relation of Power and sfc with engine rpm from PLPT result

3.2 CIRCUIT FOR DFE AND STABILIZED 5V SUPPLY: The tractor battery (12V) has been used as power source of DFE. As the voltage of the battery of the tractor fluctuates during running and due to negligence in proper maintenance and timely charging of battery, availability of constant voltage from tractor battery is generally far from reality (Mondal, 2004). The flowchart of system is given in Fig. 2. But for DFE a constant supply of 5V DC was required, which was obtained by designing a stabilizer circuit, given in Fig. 3.

3.3 SOFTWARE FOR DFE: A program was written for the DFE using 89C51 assembly language. The program has been written with different module to minimize the error. For every possible hardware software interface (like proximity switch-microcontroller program, throttle position sensor- microcontroller program etc.) program was written separately and tested separately to minimize the error in every step. At last all the part programs were combined in a final program.

3.4 HARDWARE OF THE DFE: This DFE has been developed by microcontroller, analogue to digital converter, rotary potentiometer and a proximity switch (Fig. 4). Engine speed signal input has been given through D type flip-flop latch to microcontroller. Differential analog voltage input is given to pin 7 and 8 of ADC, whereas supply voltage (5V) is given to pin 20 of ADC. For supply of digital output to microcontroller from ADC pins are used and for read and write signal pin 2 and 3 are used respectively (Mondal, 2004). 640 KHz frequency clock input is given to pin 4. Pin VCC is used to supply 5V DC power to microcontroller. Pin GND is used as ground. Liquid Crystal Display (LCD) output of the tractor performance also provided as aid to progressive farmers and researchers to have a better understanding of detailed tractor performance.

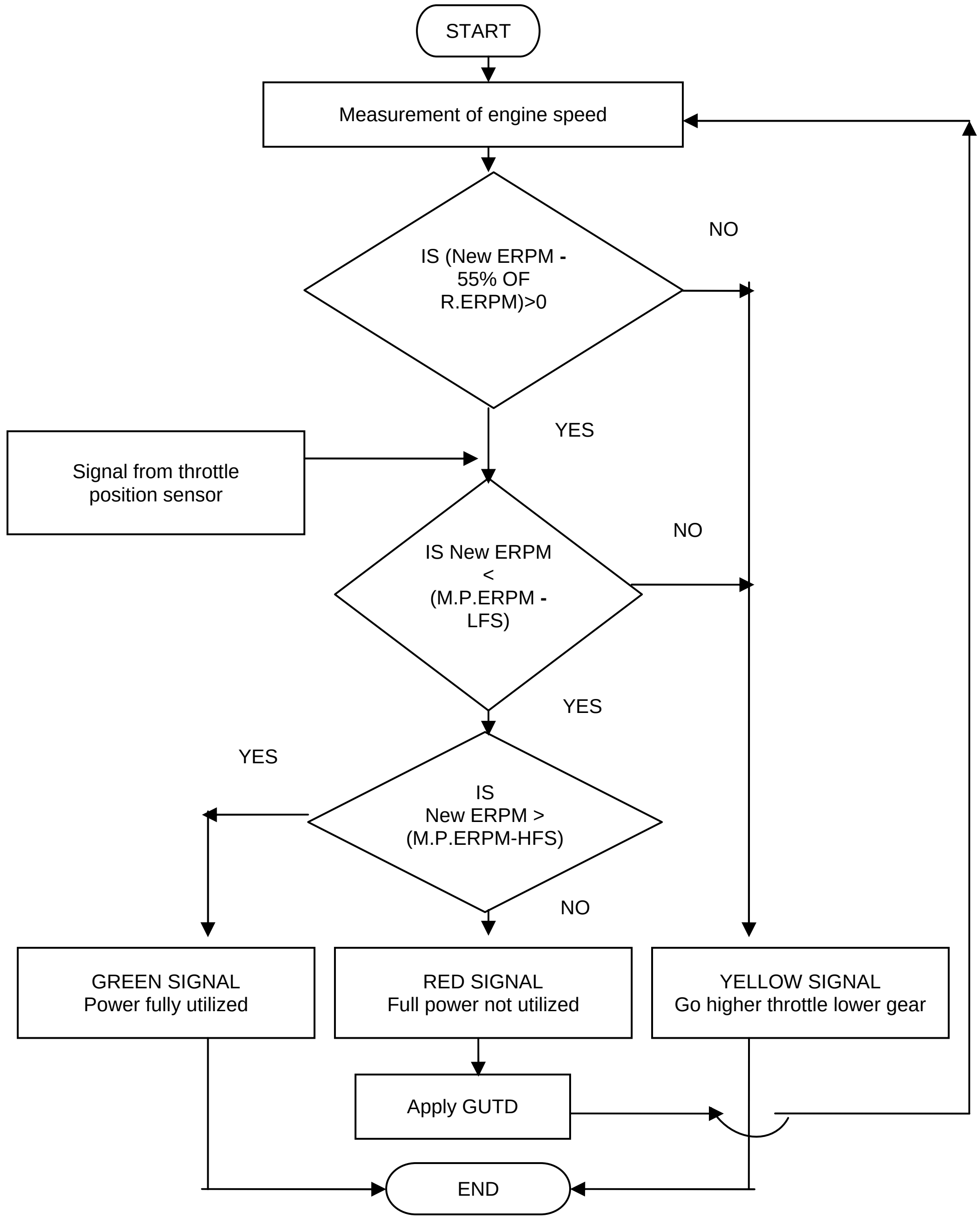

Fig. 2 Flowchart of DFE

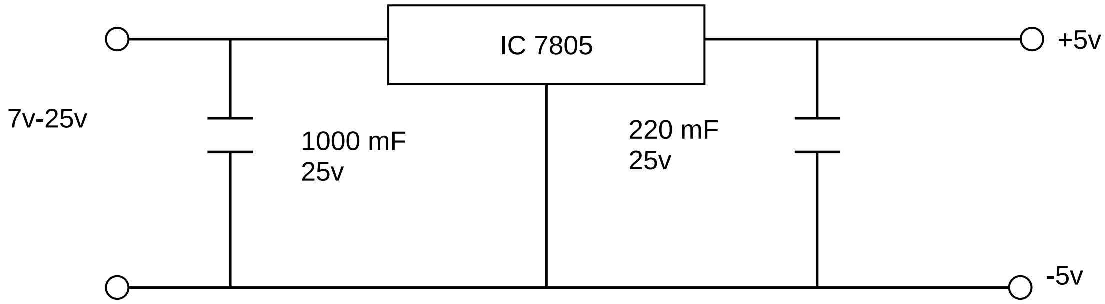

Fig. 3 Voltage stabilizer circuit

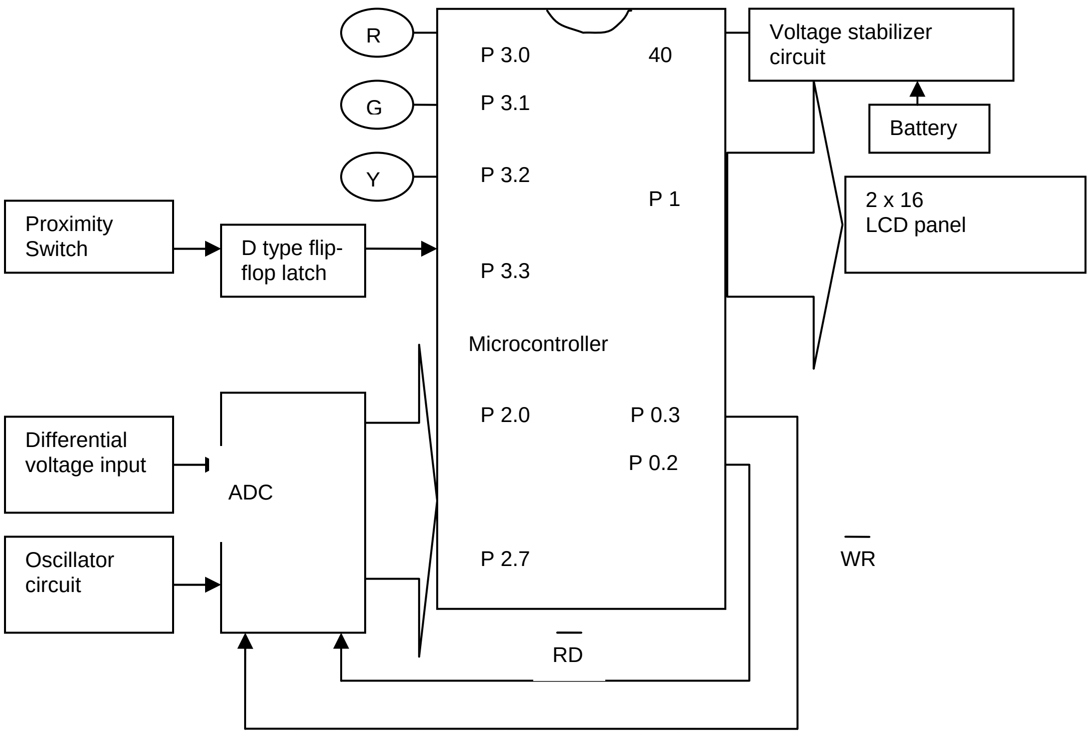

Fig. 4 Schematic diagram of DFE

3.5 SENSING OF ENGINE SPEED: Engine speed was measured by an inductive type proximity sensor (Fig. 5). Inductive type proximity sensor has been selected for their ability to operate in field condition and their metal-sensing applications are nearly endless. Without any moving parts they are not subject to wear and, with proper setup, their usually rugged design allows for an extensive lifespan. Most of the inductive sensors are capable of withstanding the buildup of contaminants such as cutting fluids grease and non-metallic dust, both in the air and on the sensor itself, which are limiting factor for other sensors (Mondal, 2004).

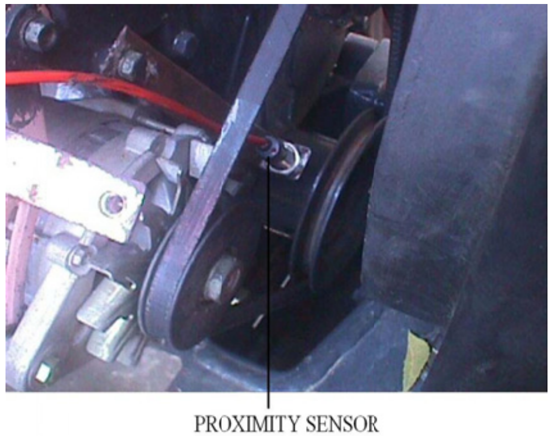

Fig. 5 Proximity sensor mounted on pulley in front of the engine

3.6 THROTTLE POSITION SENSING: A throttle lever was developed to mount the potentiometer, which sensed the throttle positions (Fig. 6). Analog signal from throttle position sensor is send to microcontroller after converting it to digital signal by ADC. It works on successive approximation principle. Signals from proximity sensor and the potentiometer were fed to micro-controller after suitable processing.

Fig. 6 Throttle position sensor

3.7 VISUAL SIGNAL SYSTEM OF DFE: Keeping in mind the low education level of Indian farmer, a simple Red-Green-Yellow signal system has been developed for DFE (Fig. 7). DFE gives red signal when engine power was not fully utilized which means ‘gear up throttle down’ is required. Green signal comes when power matches with load after moving to higher gear and subsequent reducing the throttle. Yellow signal comes when throttle is reduced too much or much more higher gear has been selected than the load. Yellow signal indicates reverse action i.e. ‘gear down throttle up’.

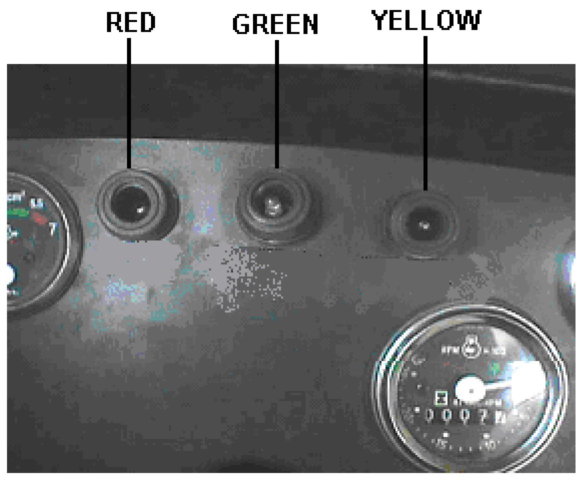

Fig. 7 Visual signal system on dashboard of tractor

4. CONCLUSION

1. Engine characteristics has been used to provide a platform to develop the DFE by using microcontroller, ADC, rotary potentiometer etc. Visual colour coded light signal, suitable for operators with low educational status has been used to provide as an aid for selection of best matching throttle and gear. LCD out put option also has been added for better understanding of the tractor performance, suitable for progressive farmers, academicians and researchers.
2. PLPT test with 5 % interval has been used to map the engine characteristics. Prediction equations of MPERPM, HFS and LFS with varying throttle positions, developed by second order polynomial regression analysis, fed to microcontroller to estimate necessary parameters for any intermediate throttle position during testing.

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