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# Testing and performance analysis of Digital Fuel Economizer for Tractors

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## ABSTRACT

Gear-up-throttle-down (GUTD) technique as a solution to match the load on tractor during field operation for better fuel economy. Experiments have proved that GUTD approach can save 20 to 30% fuel. Previously a DFE has been developed 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. Now detailed performance analysis in laboratory as well in real-time field condition are required. Therefore the prime objective of this paper was to testing and performance analysis of digital fuel economizer (DFE) system. Dynamometer testing showed that DFE successfully identified minimum fuel consumption zone and resulted in 7.1 to 15.8% fuel saving for different loading conditions. Field experiment with two bottom mould board plough showed maximum 2.6 to 15.8 % fuel saving for different depths of operation. Experiments showed that with full load condition scope of DFE is very limited.

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

## 1. INTRODUCTION

Engineers and scientists are continuously engaged to minimize fuel consumption of tractors globally. Literature search proved that many scientists investigated Gear-up-throttle-down (GUTD) technique as a solution to match the load on tractor during field operation for better fuel economy. Experiments have proved that GUTD approach can save 20 to 30% fuel (Schrock et al., 1982; Chancellor and Thai, 1984; Wang and Zoerb, 1984; Zoerb, 1984). Kotzabassis et al., (2000) gave a nice conception of GUTD system. But efficient application of GUTD system during tedious field operation is very difficult (Mondal, 2004). A tractor with a planetary transmission was equipped with an axle torque sensor and with a control handle by which the operator indicated the desired forward speed. A hard-wired control system was developed which used these two input signals and varied both transmission ratio and engine speed to give either the most fuel-efficient operating conditions at the forward speed desired or the highest rate of drawbar work, within the power capabilities of the tractor engine. Preliminary field tests showed a 5 to

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12% decrease in fuel consumption from that obtained by the most efficient of the two professional operators taking part in the tests (Chancellor and Thai, 1983; Chancellor and Thai, 1984). Another microcomputer-based gear selection aid has been developed and tested. Performance was predicted in alternative gears, and the optimum gear was chosen to minimize fuel flow subject to loading constraints (Schrock et al., 1986). Grogan et al., (1987) developed an instrumented tractor with an on-board microcomputer to measure engine load, engine speed, wheel slip, fuel consumption, draught, and hitch forces. Analysis indicated that farmers could have reduced fuel consumption of 15–27% by practicing "shift-up, throttle-back"; i.e. by shifting to a higher transmission gear and reducing the engine speed to maintain a nearly constant forward travel speed. Actual fuel consumption dropped from 11·3 to 20·0% in controlled field tests using this tractor operator information feedback system. Scarlett (1993) reviewed tractor control system developments and proposed a system for the integrated control of tractor engine, transmission and implement hitch control sub-systems, to address these perceived restrictions. It was speculated that a control system of this type could increase tractor operational efficiency by 15–20%.

Previously a DFE has been developed 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. Now detailed performance analysis in laboratory as well in real-time field condition are required. Therefore the prime objective of this paper was to testing and performance analysis of digital fuel economizer (DFE) system.

## 2. MATERIAL AND METHODS

**2.1 DYNAMOMETER TESTING OF DFE:** Engine speed (ERPM) has been measured by proximity sensor and rated ERPM (RERPM) also considered. Max. power ERPM (MPERPM), lower factor of safety (LFS) and higher factor of safety (HFS) values are selected by microcontroller. Preliminary testing of DFE has been done in Dynamometer Lab. During test throttle as well load were varied. For a particular load, throttle positions were changed in descending order. Similar way tests were conducted for other two loads also and results were recorded. The new DFE understood the changes and corresponding signals were produced in most of the cases successfully. Due to vibration some errors came.

**2.1 FIELD TESTING:** DFE has also been evaluated in actual field condition with average moisture content of 11.5% and cone index of 820 kPa by operating the tractor with a two bottom mouldboard plough for four operating depths. Auxiliary fuel tank has been used to measure fuel consumption during field testing.

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 |

## 3. RESULTS AND DISCUSSION

**3.1 RELATIONSHIP OF THROTTLE SELECTION AND ROTARY POTENTIOMETER**: To check the relationship of throttle selection and rotary potentiometer the output voltage has been recorded against the increasing throttle position with 10% interval, starting from 40% to full throttle. The result has been presented in Fig. 1. It has been noticed that a highly linear relationship exists between these two parameters, which is governed by the following equation:

Output voltage = 0.014 x Throttle position (%); ($R^2$ = 1) (1)

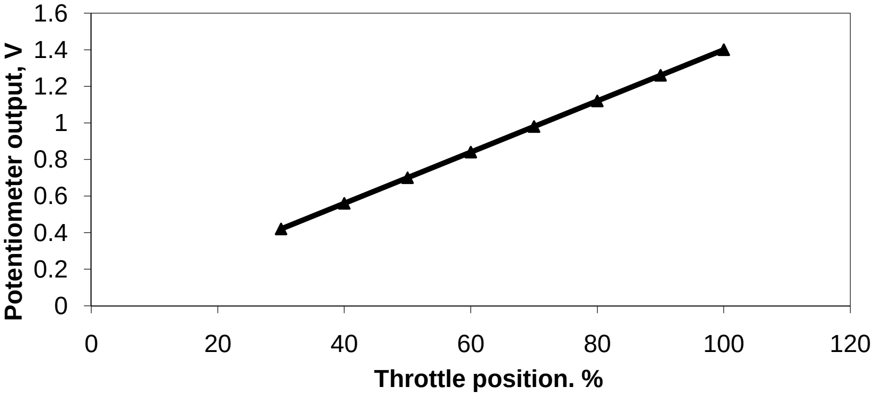

**Fig. 1 Relationship between throttle position and rotary potentiometer reading**

**3.2 RELATIONSHIP BETWEEN THROTTLE POSITION AND MPERPM**: Values of MPERPM corresponding to 50% to 100% throttle have been plotted in Fig 2. MPERPM has been found highly correlated with throttle position. A second order polynomial regression analysis has been done to know the relationship. MPERPM has been related with throttle position (T) with equation 2. This equation has been fed to microcontroller and used to predict the MPERPM for any intermediate throttle position during the experiment.

MPERPM = -0.0541 x $T^2$ + 32.694 x T - 484.04; ($R^2$ = 0.9997) (2)

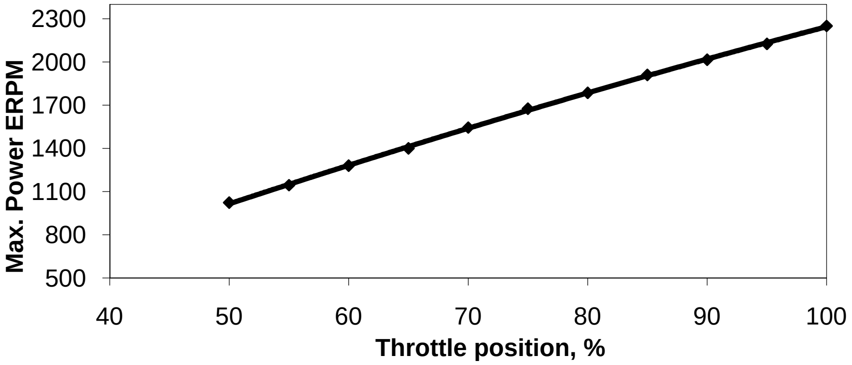

**Fig. 2 Relationship between throttle position and MPERPM**

**3.3. RELATIONSHIP BETWEEN THROTTLE POSITION WITH HFS AND LFS:** As previously told, that LFS and HFS have been selected on the basis of result of Part load part throttle test (PLPT). This selection procedure is very critical for proper functioning of DFE. Narrow band would make DFE too sensitive to operate in a easy manner, where as excessive wide band will vanish the benefit of DFE. So selection of LFS and HFS requires thorough understanding of the behaviour of engine during different segment of PLPT as well as experience of designer. After careful selection of HFS and LFS, values of HFS and LFS have been plotted against throttle positions (T) in Fig. 3 & 4. To establish the relationship of HFS and LFS, with throttle position second order polynomial regression analysis has been carried out. Equations 3 & 4 have been fed to microcontroller to predict values of HFS and LFS for any intermediate throttle position during experiments.

$$HFS = -0.0159T2 + 3.041T - 91.949; (R^2 = 0.9822) \quad (3)$$

$$LFS = -0.0046T2 + 0.9996T - 3.2168; (R^2 = 0.9946) \quad (4)$$

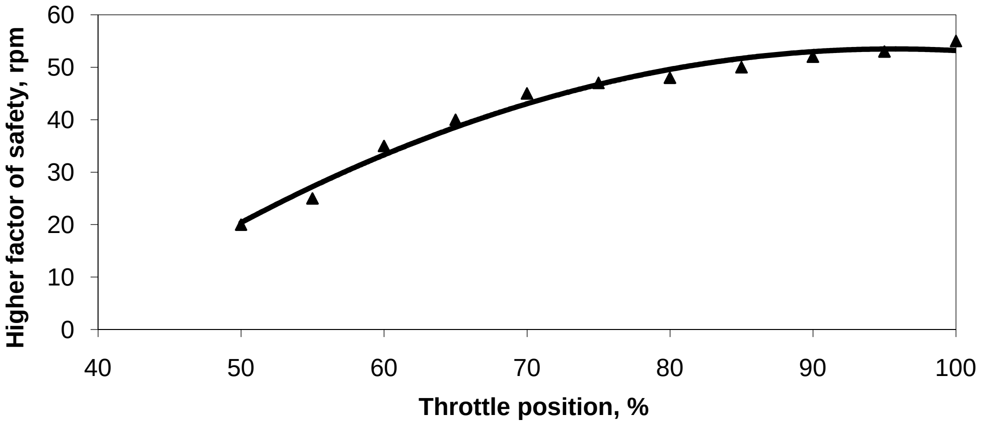

**Fig. 3 Relationship between throttle position and HFS**

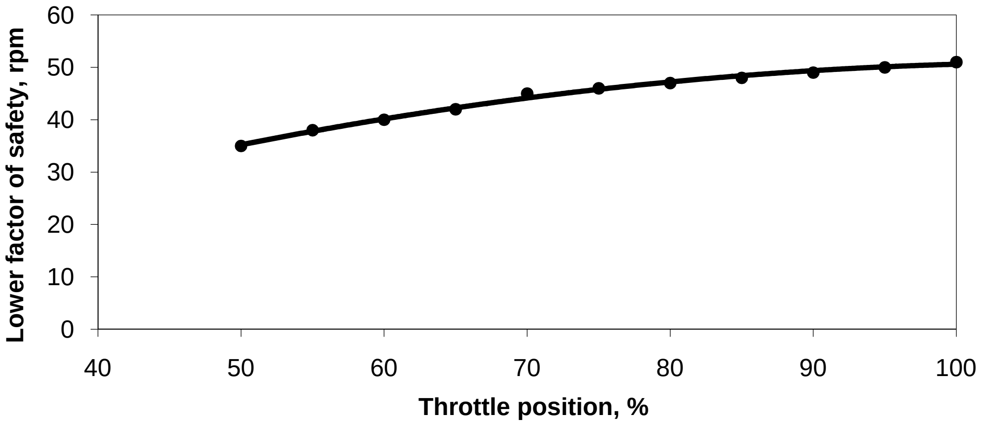

**Fig. 4 Relationship between throttle position and LFS**

**3.4 DYNAMOMETER TESTING OF DFE:** During dynamometer test of DFE three loads were selected. Results are available in Table 2. With 23.5 kg-m load maximum 15.8 % reduction in sfc was possible, where as DFE given 11.7% and 7.1% fuel saving for 29 kg-m and 37.2 kg-m load, respectively. Higher load produced less saving in fuel as higher loads automatically matched with high throttle setting. So with full load or nearly full load DFE has very little scope of working.

**Table 2. Dynamometer test result of DFE**

| Test No. | Load on PTO, Kg-m | Initial Throttle position, % | DFE Indicated throttle position, % | Initial sfc, gm/hp-hr | Final sfc, gm/hp-hr | Maximum fuel saving, % |
|---|---|---|---|---|---|---|
| 1 | 23.5 | 100 | 57 | 211.5 | 178.2 | 15.8 |
| 2 | 29 | 100 | 72 | 198.4 | 175.2 | 11.7 |
| 3 | 37.2 | 100 | 94 | 184.2 | 171.2 | 7.1 |

**3.5 FIELD TEST RESULTS OF DFE:** Field test result of DFE with two bottom mould board plough has been given in Table 3. It has been noted that DFE showed maximum 15.8 % fuel saving for 8 cm depth of operation, where as only 2.6% saving was recorded for 20 cm depth of operation. So it has been established from test result that full load condition give no or very little scope to DFE to show its function. During field test DFE also guided to select the matching gear along with throttle, which was not possible during dynamometer testing. Field test revealed the complete benefit of DFE. It has been noted that DFE not only saved fuel for 8 cm depth of operation, but also increased the field capacity by 59.3%. For 20 cm working depth gain in fuel saving (2.6%) has been almost nullified by loss in field capacity (-2.7%). So during part load operation only DFE saves fuel as well as increases work rate, which multiplies the fuel saving benefit.

**Table 3. Field test result of DFE with two bottom mould board plough**

| Test No. | Depth of operation, cm | Initial selection | | Selection by DFE | | Initial Ground Speed, Km/h | Final Ground Speed, Km/h | Change in Field capacity | Max. Fuel saving, % |
|---|---|---|---|---|---|---|---|---|---|
| | | Gear | Throttle, % | Gear | Throttle, % | | | | |
| 1 | 8 | L1 | 100 | L4 | 64 | 2.95 | 4.7 | 59.3 | 15.8 |
| 2 | 12.5 | L1 | 100 | L3 | 73 | 2.92 | 4.4 | 50.7 | 11.7 |
| 3 | 15 | L1 | 100 | L2 | 75 | 2.92 | 3.42 | 17.1 | 8.5 |
| 4 | 20 | L1 | 100 | L1 | 95 | 2.91 | 2.83 | -2.7 | 2.6 |

## 4. CONCLUSION

1. During dynamometer test with 23.5 kg-m load maximum 15.8 % reduction in sfc was possible, whereas DFE gave 11.7% and 7.1% fuel saving for 29 kg-m and 37.2 kg-m load, respectively. During field test with two bottom mould board plough, DFE showed maximum 15.8 % fuel saving for 8 cm depth of operation, where as only 2.6% saving was recorded for 20 cm depth of operation.
2. The usefulness of DFE is predominant in part load conditions when part throttle operation is possible. Furthermore, the DFE can recognize the minimum sfc. zone (green signal area) for every throttle setting.

## ACKNOWLEDGMENTS

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