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New approach to measure instantaneous angular behaviour of a dual mass flywheel

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The Dual Mass Flywheel (DMF) can be the cause of noises and chock strong enough to be perceived and disturb vehicle occupants. The analysis of this mechanical phenomenon is quite difficult because it requires measurement on a rotating wheel. Real time angular measurement can be performed by using a new system called FURD, developed by D2T, which requires only two analogue signals coming from inductive sensors mounted on the flywheel and the gearbox. In addition with a crown information picked up from the engine, it is possible to get in real time the absolute angular position of the DMF in the friction curve and so determine more easily the origin of noises and disturbances.

Keywords: DMF, Dual Mass Flywheel, Shaft phase ,Angular deviation

INTRODUCTION

The analysis of angular behaviour of a Dual Mass Flywheel (or any other flywheel) is very important to understand and identify noises that occur in the transmission. The reduce space between engine and gearbox doesn't allow any complex instrumentation like the use of an encoder for instance. Actually, one of the easiest ways to evaluate the angle deviation of the flywheel is based on speed measurement, the difference of speed between engine and gearbox is measured and integrated. This solution requires a post processing and doesn't provide efficient results because of the shift introduce by calculation errors. This paper presents a new method to measure the angle position of the flywheel based on a system called FURD, which computes in real time the angular deviation, and make easier the friction analysis. The second part of this paper presents the general working principle of the FURD.

ANGULAR DEVIATION MEASUREMENT

MEASUREMENT SETUP

Two inductive sensors have been mounted on the engine, one on the 121 teeth self-starter wheel and the other one on a 28 teeth cogwheel of the drive shaft. Those analogue signals are processed by the FURD and the deviation angle is then analysed on a dedicated acquisition system.

DUAL MASS FLYWHEEL BEHAVIOR

Figure 1 represents the Dual Mass Flywheel behaviour on a vehicle in third gear during a deceleration phase. The FURD output is scaled to 50° for 10 Volts. This real time result allows a direct analysis of the clutch friction.

During the deceleration phase, the friction oscillates following the engine acyclism frequency. It is possible to identify in the slope the precise instant when the friction

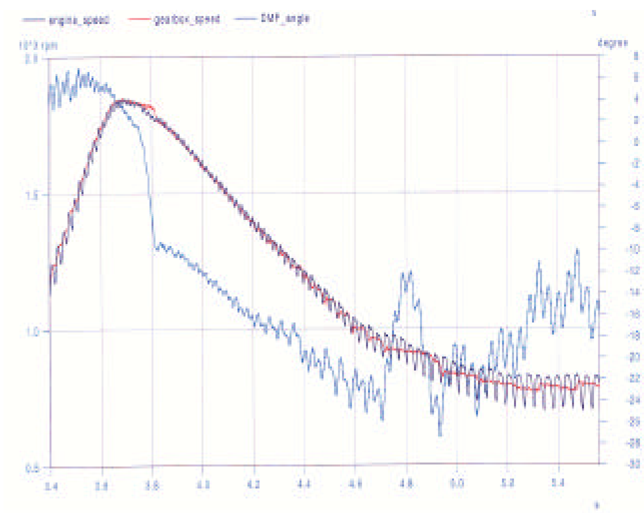

Figure 1 – DMF behaviour during deceleration

filtering becomes active and efficient. Under 1000 rpm, for instance, the gearbox speed starts to be well filtered, there is a balanced position where the friction is fully efficient to damp acyclism.

It is possible to go a bit deeper in this analysis and to correlate noises or shocks with the friction angle. In fact the FURD gives the angular displacement of the flywheel, if this information is combined with the image of the engine torque, it is possible to know quite precisely, the position of the flywheel in the friction curve.

ANGLE OF THE CLUTCH FRICTION

The angular behaviour of the flywheel is compute with the FURD between the 121 teeth of the self-starter wheel and the 28 teeth cogwheel of the drive shaft. To get an image of

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the engine torque, the torque recovering rod is instrumented with a strain gauge.

Measurements are made on a vehicle starting in first gear, the figure 2 illustrates the behaviour of the flywheel and the global vibrations measurement. Those vibrations have been measured with an accelerometer on the gearbox case.

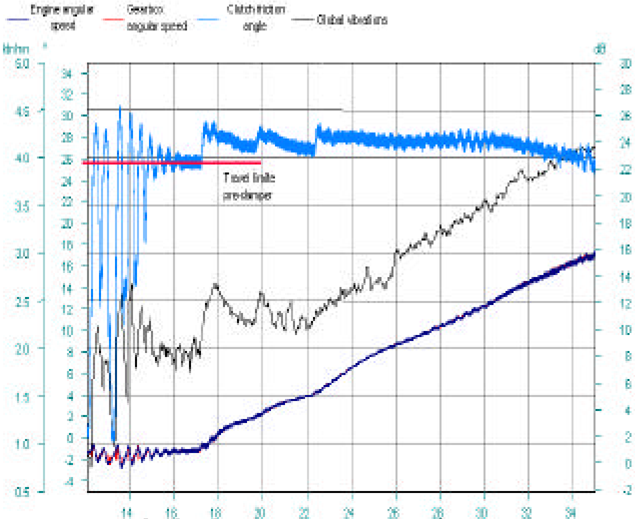


Figure 2- angle displacement, starting in first gear.

The strong vibrations measured with the accelerometer are directly correlated with the oscillations of the flywheel, the noise induced by those vibrations is due to the flywheel that can't compensate the engine torque and oscillate until the low torque stage stop of the damper. Noises generated by those shocks are now easily and directly identifiable.

The next figure is a representation of the engine torque, picked up on the recovering torque rod, versus the clutch friction angle.

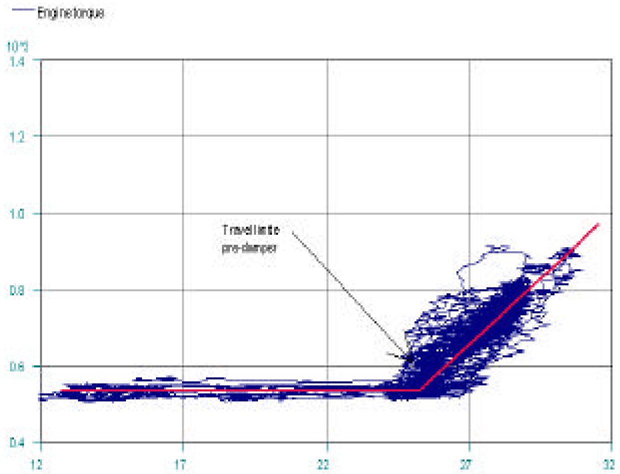


Figure 3 – Torque versus clutch friction angle

The same measurement can be done at different gear and speed, by this way, it is possible to identify and to correlate noises and shocks with critical points of the friction curve like the pre-damper stop, any changing on damper torque slope…

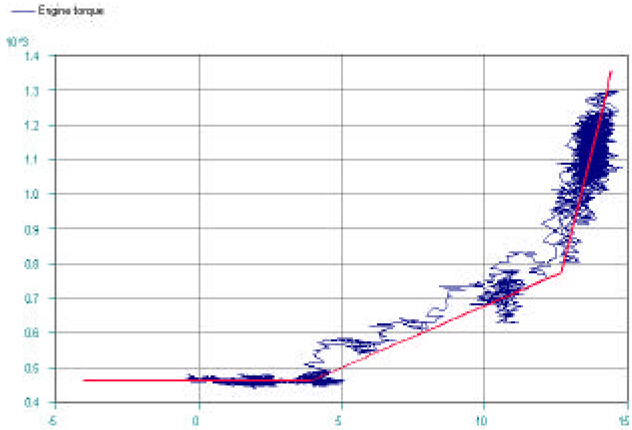


Figure 4 – Torque versus clutch friction angle

Figure 4 has been obtained in second gear with a strong acceleration

CONCLUSION

This first part demonstrates through an application the use of the FURD. By simply parameterise the number of teeth connected to the two inputs channels and the desired output scale, analyze of the dynamic angle evolution between two wheels becomes very easy. In this case, the friction curve can be measured easily and dynamically, this information is very important because until now it was not possible to correlate any noise or shocks to the position of the flywheel in the friction curve. This may help to find solution to eliminate those disturbances.

The second part of this paper is dedicated to the measurement principle of the FURD.

FURD WORKING PRINCIPLE

The computation based on the integration of the difference of speed between two wheels was not providing good results due to quantification errors, which introduced a shift on the result. The FURD working principle is based on a phase measurement.

TYPICAL SPEED SIGNAL WAVEFORMS

Instantaneous variations of speed during one engine revolution, due to acyclism for instance, combined with different number of teeth on each wheel gives two analogue signals which periods vary at each tooth. The relationship between the angular velocity of the wheel and the period leads to

$$T_i = \frac{2p}{w_i \times N} \qquad \text{Eq(1)}$$

Where N is the number of teeth of the wheel and ω_i the instantaneous velocity. Like shown on the Figure 1, the speed of engine and gearbox have the same average values but different instantaneous variations. (Figure 1 illustrates also this acyclism phenomenon)

Accordingly to equation 1, the instantaneous variation of speed results in a modulation of signals coming from inductive sensors. The FURD conditioning stage process analogue signals into TTL thanks to a zero crossing detector, Figure 5 illustrate the corresponding periods of signals coming from the engine and the gearbox

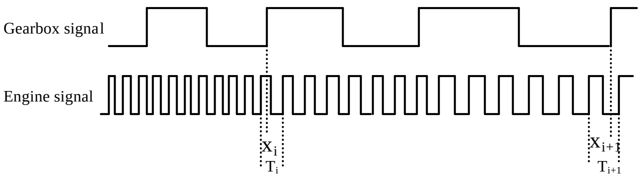


Figure 5 – processed signals coming from gearbox and engine sensors

The currently used method for measuring the angular deviation was based on instantaneous velocity of both wheels. This method, requiring post processing, was not giving good results due to quantification and measurement errors. To avoid those drawbacks and to make real time analysis, the instantaneous velocity should not be used but signals phase gives better results.

PHASE MEASUREMENT

To compute the angle deviation, it is first necessary to detect the lowest input frequency of the two channels and to count the number of periods seen during two periods of the slowest channel. Like shown on figure 5, during two periods of the gearbox signal, there are 12 complete periods of the engine signals. By a complex counting system, it is possible to measure precisely the lengths Xi, and Yi, where Xi is the time between the rising edge of the highest frequency signal and the following rising edge of the lowest frequency signal, and Yi the time between two rising edge of the highest frequency signal including a rising edge of the lowest frequency signal. By this way, the FURD measures very precisely, the number of pulse on the engine channel:

$$N_{pulse} = N_i + \frac{X_{i+1}}{Y_{i+1}} - \frac{X_i}{Y_i} \qquad \text{Eq(2)}$$

N_i is the number of complete periods (12 in our example) between 2 edges of the slowest signal.

By knowing very precisely the number of pulse on each channels and the number of teeth of each wheel, quite simple calculation gives the angle seen on each channel and so the instantaneous angular difference.

$$\Delta_{inst} = \frac{N_{pulse\_gearbox} \times 360}{N_{teeth\_gearbox}} - \frac{N_{pulse\_engine} \times 360}{N_{teeth\_engine}} \qquad \text{Eq(3)}$$

All Δ_{inst} are then accumulate to get the angular deviation between the two channels.

$$Deviation = \sum_{0}^{\infty} \Delta_{inst} \qquad \text{Eq(4)}$$

This measurement method combined with high frequency counting stage provide an angular measurement better than 0.01 CA (Crank Angle), this accuracy is obtained independently of the number of teeth of the wheel. Even with a 20 marks wheel or with a 720 marks encoder, the accuracy of the angular measurement is excellent. The interest of using a wheel with a great number of teeth is to improve and increase the bandwidth spectrum to be analysed.

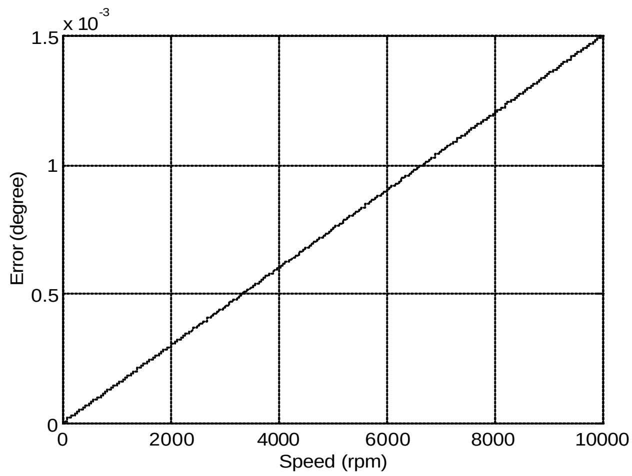
ERRORS INTRODUCED BY THIS ALGORITHM

Counting stage errors

As explain before, it is necessary to measure two different times, X_i and Y_i (see Eq(2)) to get a very precise idea of the number of pulse seen on each channel. This length measurement can be realised with a high frequency counting clock F_{clk}. This quantification introduce an error, which is minimised because of the ratio between X_i and Yi. This error is independent from the number of teeth, which explain that the accuracy is still good with only 20 teeth. This error is only function of two factors, the engine speed and the counting clock frequency.

$$Err = \frac{6 \times V}{F_{CLK}} \qquad \text{Eq(5)}$$

V is the engine speed in revolution per minute. Because of the structure of Eq(2), this error is not accumulated , terms being successively added and subtracted. Figure 6 illustrates this error curve with a 40Mhz counting clock.



The number of teeth doesn't affect the accuracy of Eq(2) as said before, but to compute Eq(3), the resolution of the wheel is quantified and introduce a typical numerical error. In fact the following operation has to be done to compute Eq(3) :

$$Reso = \frac{360}{N_{teeth}} \qquad \text{Eq(6)}$$

For speed convenience, this operation is realised in fixed arithmetic, with 16 bits length to code the decimal part. This gives an quantification error that is less than 7,63 10^{-6}

CA. Moreover, this error is made at each calculation and hence accumulated. But, because of its repeatability, it can be quite easily corrected. In fact, as the quantification error is perfectly known, regarding the number of bits used, a correction value can be applied on some points during one revolution to be sure the angle seen on each channel during is equal to 360 CA exactly, this compensate the drift due to quantification error integration. The maximum error introduced in one round is equal to the correcting value applied to get the 360 CA angle. The following curve represents this error when using a 16 bits quantification :

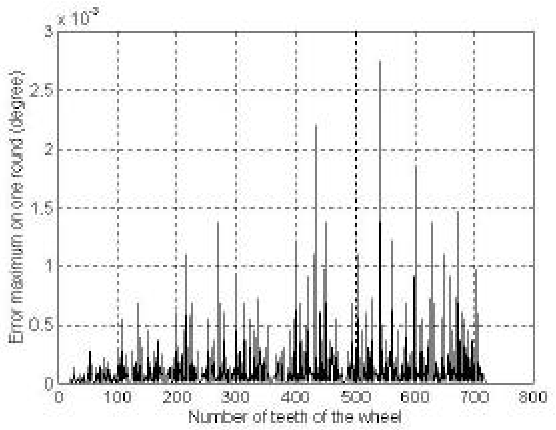
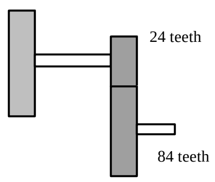


Figure 7 – Maximum numerical error

EXTENSION TO UNSYNCHRONOUS WHEEL

To work, this method was based on the hypothesis that the 2 wheels were synchronous, assuming their two mean speed were equal. This measurement algorithm can easily be extended to wheels which mean speed are linked through a coefficient. In a gearbox for instance, the relation between the main shaft speed and other secondary shafts are given by different reducing speed ratio. The following schematic represents two cogs in a gearbox :



The speed of Cog B is given by the following relation :

$$w_{cogB} = C \times w_{cogA} \quad \text{Eq(7)}$$

where C is the reducing speed ratio, 0,285714 in our case.

Eq(3) gives the angular instantaneous difference obtained by phase comparison. The same phase comparison can be applied here. It can be demonstrated that by applying the reducing speed ratio on the resolution of one channel, the instantaneous angular difference can be computed.

$$\Delta_{inst} = \frac{N_{pulse\_cogA} \times 360}{N_{teeth\_cogA}} - \frac{N_{pulse\_cogB} \times 360}{N_{teeth\_cogB} \times C} \quad \text{Eq(8)}$$

The major error introduced here is coming from the precision of the definition of the reducing speed ratio. In fact, the number of decimal digits is limited, and so introduce an error which can’t be compensated. 6 decimal digits are used in the FURD to a minimise the drift introduced by calculation. This drift is however relatively low and doesn’t affect seriously measurements if the analysis has not to be done on a long time.

BLOCK DIAGRAM OF THE FURD

The FURD handles also a selectable output scaling to adjust the gain and fully use the scale of the acquisition system for instance. The other important possibility of the FURD is the measurement of angle deviation between two wheels on two different shafts. The user can parameterise a coefficient, which compensate the difference of speed between the two wheels.

CONCLUSION

This paper presents the FURD, a new system to measure angular deviation between two rotating wheels, through a typical application, which was not easily realisable before. In addition with a crown measurement on the engine, it is possible to know and to analyse the absolute position of a Dual Mass Flywheel in the friction curve. The FURD has the advantage to give real time dynamic measurements with a very good accuracy. Its adjustable output scale allows the user to measure a high range of deviation and always fully use the scale of his acquisition system. One other application using the speed compensation coefficient can be the analysis of the crown transmission on the entire cinematic chain by measuring the angular deviation between the engine and some cogs in the chain.