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SIMPLIFIED MODELLING METHOD TO PREDICT OUTPUT SPEED OF AN OVERRUNNING CLUTCH USING ADAMS/SOLVER SUBROUTINE

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ABSTRACT

A study on working principle of an overrunning clutch was conducted and a set of simplified mathematical equation was derived for different working conditions of the mechanism. This paper presents a method of simplified modelling to predict the output speed by applying the derived mathematical equations using user-written subroutine in ADAMS/Solver. The model was assumed to have negligible slipping torque and static friction. The subroutine written and compiled in C++ language using Microsoft Visual Studio is programmed for the modelling of the simplified model in ADAMS/View to simulate the mechanism. A model of an overrunning clutch using actual dimensions including rollers was modelled and simulated using ADAMS/View for comparison purposes. The average magnitude of output speeds was found to be identical but the trends were slightly different due to slipping torques.

Keywords: overrunning clutch, one-way clutch, output speed.

INTRODUCTION

Overrunning clutch is an essential element that can be found in various mechanical equipment such as engine starter, factory automation, or bicycle. It is beneficial for a mechanism which requires unidirectional output motion from reciprocating input motion. The overrunning clutch also has another characteristic that is required in certain application, such that when the output torque exceeds a certain threshold value, it cuts off the torque transmission to protect output mechanism from being broken due to the excess input [1-2].

The overrunning clutch has two operating modes, namely engagement and disengagement. During freewheeling (disengagement), the clutch's operational behaviour can be considered to be the same as a roller bearing. In a standard bearing, summation of rolling friction, sliding friction, seal friction, and drag loss represent the friction torque [3]. K. Liu *et al*. [4] have conducted a study on the rolling friction of this type of clutch using Hertzian contact theory. The study concluded that the major component of the rolling friction was caused by elastic hysteresis and viscous shear. The rolling friction is relatively small in normal condition when compared to during running under low-speed condition. Another study has also been done on the sliding friction of a clutch to investigate the influence of roller size and number of rollers on the sliding friction [5]. The study concluded that the smaller size and higher number of rollers resulted in lower friction. The friction was also significantly low in a full-film lubrication condition.

YC Chen *et al*. [6] have studied the effect of design parameter on the slipping torque of an overrunning clutch. During engagement, the slipping of inner and outer race will cause a lag in power transmission due to the slipping torque. The study showed that the increase in friction coefficient and number of rollers, and the decrease in roller size of the clutch has resulted in a higher slipping torque.

In this study, a user-written subroutine was written in ADAMS/Solver to predict the output speed of an overrunning clutch. The method is to simplify the simulation process of the clutch in a complex mechanism. Oscillatory motion is used as the input and slipping torque and static friction are neglected in this study. The model will be simulated using variable inertia values and validated using a model of the clutch.

SIMPLIFIED MATHEMATICAL EQUATIONS OF AN OVERRUNNING CLUTCH

An overrunning clutch consists of an inner race, an outer race, a few rollers, and springs. The inner race is rigidly connected to an input shaft which transmits the input torque to the outer race, which is rigidly connected to the output mechanism. The springs retain the rollers in the wedge space between inner and outer race. K. Liu *et al*. [5] described that when a reciprocating input motion was applied, the clutch would convert it into a unidirectional rotational output. The inner and outer race would disengage if the input rotated in the opposite direction, or the angular velocity of the driven output was higher than the input.

Based on the working principle, we understood that an overrunning clutch have two modes of running, such as engagement and disengagement. There are two conditions during freewheeling, which are freewheel during idle, and freewheel during running. These conditions are determined by initial condition and angular velocity difference between the inner and outer race. The mathematical equations [7] are shown below, where the angular velocities of the inner race and outer race are denoted by ω_{in} and ω_{out}, respectively. The first condition is the engagement of inner and outer race which only occurs when the angular velocity of the outer race is smaller than the inner race. It can be defined as:

$$\omega_{out} = \omega_{in} \text{ when } \omega_{in} > 0 \ \& \ \omega_{in} \geq \omega_{out} \quad (1)$$

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If the inner race rotates in the opposite direction while the outer race is in stationary or idling, the outer race remains stationary. This can be shown as:

$$\omega_{out} = 0 \text{ when } \omega_{in} < 0 \ \& \ \omega_{out} = 0 \quad (2)$$

When the angular velocity of the outer race is the same or higher than the input race, the clutch will disengage. Consequently, the output speed will drop due to the angular acceleration which can be calculated as follows:

$$\omega_{out} = \omega_{out(t-1)} + \alpha t \text{ when } \omega_{in} < \omega_{out} \ \& \ \omega_{out} > 0 \quad (3)$$

$$T_{ex} - T_f = I\alpha \quad (4)$$

where T_{ex} is the applied torque, T_f is the friction torque, I is the moment of inertia, and α is the angular acceleration. During freewheeling, applied torque is equal to zero, so angular acceleration can be defined as follows:

$$\alpha = -\frac{T_f}{I} \quad (5)$$

Equation. (5) shows that when friction torque (T_f) value is small, the speed drop of the output race will also be small. Higher inertia (I) value is desirable in order to reduce speed drop at the output.

MODELLING AND SIMULATION

ADAMS/solver user-written subroutine model

C++ user subroutine which was written in Microsoft Visual Studio was linked to ADAMS/Solver. A user-written subroutine is required in order to simulate a simplified model. The simplified model shown in Figure-1 was created in ADAMS/View using a few simple geometrical bodies which represents an overrunning clutch component. The inertial values of inner and outer race are defined based on the actual parameters of an overrunning clutch. It is a necessary step in order to obtain a similar result with an actual overrunning clutch in the simulation. The design parameters used in the modelling is shown in Table-1.

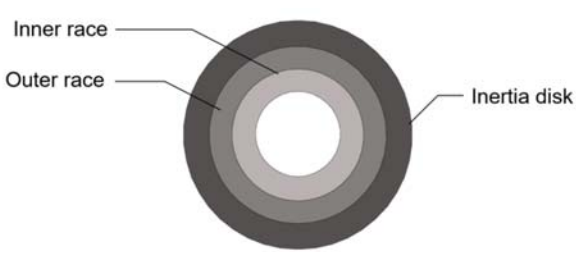

Figure-1. Simplified model of an overrunning clutch

Table-1. Design parameter for simplified overrunning clutch.

Parameter	Value
Clutch inner race diameter	30 mm
Clutch outer race inner diameter	46 mm
Clutch outer race outer diameter	62 mm

The inner race and outer race was attached to the simulation ground using revolute joints. The inertia disk was rigidly fixed to the outer race using fixed joint. In order to study the effect of inertia on the output speed, the values of inertias are varied. A fixed joint, which acts as an engaging mechanism during simulation was created between the outer race and inner race. This joint will be activated/deactivated using user-written subroutine.

A user-written subroutine was written using Consub driver subroutine to control the simulation based on the derived mathematical equations. An array of markers detects and passes the values of angular velocity of the inner and outer race to be evaluated in the subroutine. Based on specific values being retrieved from the model, the subroutine will evaluate which condition to be applied in the simulation. The user-written subroutine is shown in Figure-2.

```
// === RUNNING ===
if(wzin>0){
    c_modify("ACTIVATE/JOINT, ID=3", &istat);
    if(istat!=0)
        c_errmes(istat,"Err:Fixed Joint ON",istat,"STOP");

// FREEWHEEL during RUNNING
    if(wzout-wzin>0){
        c_modify("DEACTIVATE/JOINT, ID=3", &istat);
        if(istat!=0)
            c_errmes(istat,"Err:F/WHEEL RUNNING",istat,"STOP");
    }
// ENGAGE during RUNNING
    else{
        c_modify("ACTIVATE/JOINT, ID=3", &istat);
        if(istat!=0)
            c_errmes(istat,"Err:ENGAGE RUNNING",istat,"STOP");
    }
}

// === IDLE ===
// FREEWHEEL during IDLE
else{
    c_modify("DEACTIVATE/JOINT, ID=3", &istat);
    if(istat!=0)
        c_errmes(istat,"Err:F/WHEEL IDLE",istat,"STOP");
}
```

Figure-2. User subroutine to control the engaging mechanism.

Based on the passed angular velocity of the model, the subroutine will activate/deactivate the fixed joint applied between inner and outer race. The simulation control is defined as follows:

1. If $\omega_{in} > 0$ (counter clockwise) and,

a. $\omega_{in} \geq \omega_{out}$, then the fixed joint will activate. The inner and outer race will engage as explained in the

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overrunning clutch working condition in Equation. (1).

b. $\omega_{in} < \omega_{out}$, then the fixed joint will deactivate. The clutch disengages when outer race speed exceeds inner speed as explained in Equation. (3). The friction torque is set as constant in this simulation.

2. If $\omega_{in} < 0$ (clockwise), the fixed joint will deactivate. The outer race will disengage when inner race rotates in the opposite direction as in Equation. (2).

The model was simulated using variable values of inertia and a constant friction torque of 0.05 Nm [8]. Slipping torque and static friction are neglected in this simulation. Sinusoidal input motion was applied to the inner race to maintain a consistent angular speed input throughout the simulation. The equation for input motion used is:

$$A\sin(2\pi ft) \quad (6)$$

Where A is amplitude, f is frequency, and t is simulation time. The amplitude and frequency values in this simulation are fixed at the values of 1000rpm and 50Hz respectively.

ADAMS/view model

A model of an overrunning clutch was created using CATIA V5 and imported into ADAMS/View to simulate the real mechanism in order to compare with the user-written subroutine model. This model is considered as a complex model. Figure-3 shows the overrunning clutch that was modeled. Parameters used for the model is the same as the ADAMS/Solver user-written subroutine model as shown in Table-1. The material used in the model is steel which was applied from standard material library in the software. The model was simulated using the same sinusoidal input speed, friction torque, and variable values of inertia similar to the user-written subroutine model. The inner and outer race of the model have a constant value of inertia throughout the simulation, while the inertia value of the disk is varied.

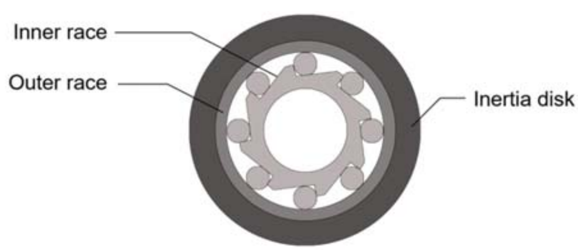

Figure-3. Complex model of an overrunning clutch with inertia disk attached.

RESULTS AND DISCUSSIONS

An ADAMS/Solver user-written subroutine was created based on the mathematical equations as shown in Equation. (1) - (3). An ADAM/View model was created to compare with the user subroutine simulation results. Both of the simulations were conducted using the same sinusoidal input motion. The total inertia value of inner and outer race and friction torque are fixed, while inertia value of the inertia disk was varied throughout the simulation.

Figure-4 shows the absolute value of input speed and the resultant output speed of the user-written subroutine model for different values of inertia. The result shows that the increase in inertia value results in the decrease of the speed drop.

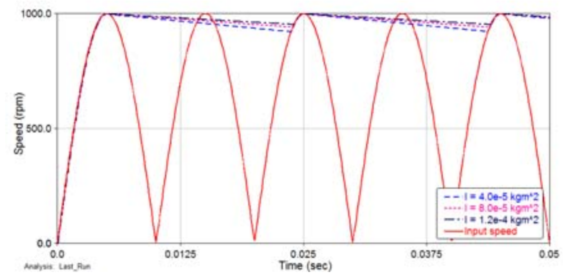

Figure-4. The effect of inertia on the output speed of user-written subroutine model.

The comparison results of the user-written subroutine and the ADAMS/View model are plotted in Figure-5. During the beginning of the model simulation, an overshoot of output speed can be observed from the ADAMS/View model. The reason is because the simulation is based on the actual engineering principle where the starting torque increases due to the static friction. In other words, higher torque is needed in order to move static inner and outer race at the beginning of the simulation. This results in a high velocity of the outer race during disengagement. The speed variation between both methods is observed to be reduced and maintained almost the same pattern during the second engagement of the inner and outer race.

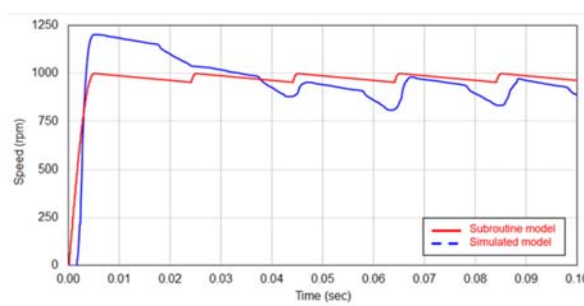

Figure-5. Comparison between subroutine and ADAMS/View model.

Figure-6 shows the difference percentage between user-written subroutine and ADAMS/View model. The percentage of error was found to be between -18% to 20%. Although this is the case, the average output speeds of both cases are found to be 977rpm for the subroutine model and 972rpm for the ADAMS/View model. The error is calculated to be 0.51% only.

Therefore, it can be concluded that the subroutine model (simplified model) can be successfully used to predict the average output speed.

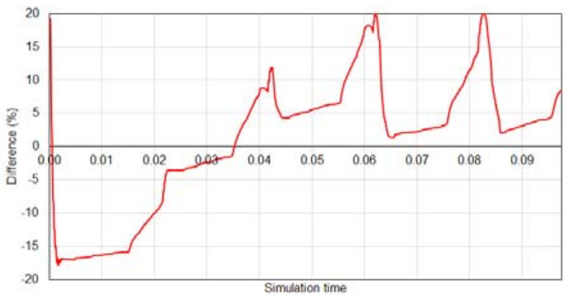

Figure-6. Difference percentage between user-written subroutine and ADAMS/view model.

CONCLUSIONS

A simplified simulation method was created based on mathematical equations of an overrunning clutch. The equation was able to give a quick prediction of the average output speed based on data input from an actual overrunning clutch. The simplified model can be used to predict the average output speed of a complicated model without involving expensive computing.

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