

Development of a Timing Chain Drive Model for a High Speed Gasoline Engine

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ABSTRACT

Engine efficiency and optimization are key aspects for automotive manufacturers. Lamborghini has particularly focus attention for reduction of time to market building up a synergic approach for new component's development using simulation, Know-how experiences, engine engineering expertise and experimental validation. In particular to reach the best results in the shortest time it is used, in the preliminary stage of development, a massive support of simulation analysis.

In the Lamborghini approach analysis and simulation has become key aspects during concept and development of timing drives. This type of activity is used to support the development of better chain timing drives focusing on improving durability, lower friction, less noise and reduced cost in less time than conventional trial and processes.

Even during the concept design phase it is useful to use a mathematical model to calculate dynamic forces and motions of a chain drive. These models are used to assess in detail the choice of drive layout, to check that component load limits are not exceeded and to make a first choice of the tensioner settings. Later, when the first prototype engines are available, measurements of timing drive sprocket motion, tensioner motion and tensioner force are typically taken. At this stage the model can be correlated to the measured data and then the correlated model can then be used to explore the potential for improvements to the timing drive during later phases of engine development.

This paper describes the correlation of a mathematical model of a complex timing chain drive for a Lamborghini V12 gasoline engine to measurements made on a prototype engine. The depth of model required and the choice of stiffness and damping values needed to give excellent agreement between calculations and measured data are discussed.

INTRODUCTION

The choice of the basic dimensions of the timing drive for a new engine is often problematic. For a high performance sports car engine with a V12 configuration this activity is particularly complicated because the high engine maximum speed, high crank nose vibration levels and aggressive cam profiles lead to high forces in the timing drive while the tight packaging of the engine in the vehicle leads to a requirement for minimum engine length. It is quite possible to design a chain drive that appears superficially to be acceptable but suffers from poor durability requiring expensive redesign and causing long delay to engine development.

To speed up the development of the timing drive a multi-body dynamic analysis is now often used during the concept design phase [1, 2, 3, 4, 5, 6, 7]. These calculations supplement the traditional design rules (such as limits on sprocket wrap angle, tensioner location, guide radius and unsupported chain span length etc.). The successful use of this kind of mathematical model at an early stage of design is a highly skilled activity because experience is required to choose the required depth of model and sensible values for stiffness and damping at numerous locations.

The mathematical model developed during the design phase can be validated by comparing measurements and calculations once a prototype engine is available to perform the required tests. It is relatively easy to measure the angular motion of each sprocket. The motion of the tensioner and the force between the tensioner and the structure can also be measured quite easily. It is possible to measure chain force directly [8] but this involves special instrumentation and while it is useful for model validation it is not a routine activity. This paper describes this phase of model development and demonstrates the degree of correlation that is possible. The mathematical model and the test process are only described briefly. The focus of the paper is on the choice of model parameters that cannot be obtained from drawings.

A correlated mathematical model of the timing drive always proves very useful during the remainder of the engine development process. In general terms the model can be used to reduce the number of physical tests required and the following are typical activities where chain drive analysis can be used.

- Component optimization (for example - choice of chain guide shape to reduce wear)
- Tensioner setting optimization (for example - to minimise friction while maintaining control of vibration)
- Engine uprate assessments (for example - quantifying the effect of a change to the cam profiles on chain force)
- Component failure investigations (for example - chain fatigue failure)

ENGINE HARDWARE AND MEASUREMENTS

Measurements of angular motion were made on each chain sprocket on the timing drive of a V12 engine with three timing chains as shown in [Figure 1](#). The primary reduction drive transferred motion from the crankshaft to an intermediate sprocket operating at $2/3$ of crankshaft speed using a duplex chain. This intermediate sprocket also served to drive the auxiliaries via a belt as shown in [Figure 2](#). On each bank of the engine both camshafts were driven by a simplex chain. Each chain had bush type construction with a pitch of 9.525mm. Each chain had a separate hydraulic tensioner with dedicated blade design.

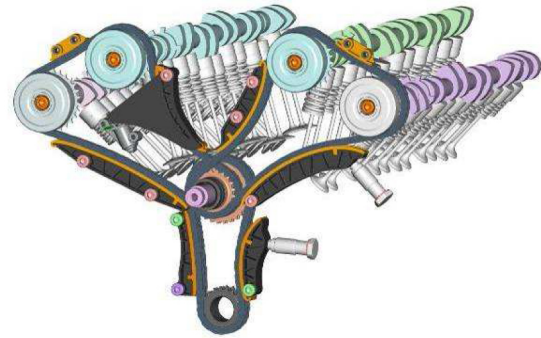


Figure 1. CAD image of V12 engine timing drive

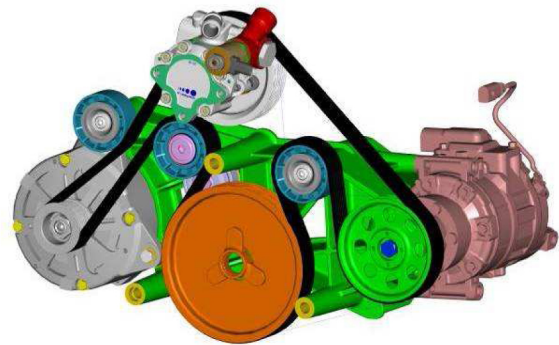


Figure 2. CAD image of V12 engine auxiliary belt drive

Measurements of the angular velocity of each chain sprocket were made using inductive probes acting on the sprocket teeth. Results are shown on graphs later in this paper.

DESCRIPTION OF MATHEMATICAL MODEL

The mathematical model of the timing drive for the Lamborghini V12 was constructed using Ricardo Software VALDYN during the engine concept design phase. This section includes a brief description of the modeling assumptions and the elements used.

The model developed during the design phase of the engine is described as the “concept model” and the model with improved agreement with measured data is referred to as the “correlated model”.

The models essentially capture the rotational dynamics of the system. [Figure 3](#) shows the complete system from the crankshaft nose through the chain drives to the 4 camshafts for the concept model. The model was excited at the crank sprocket by the crank rotational vibration and at each valvetrain by the dynamic torque resulting from spring force and inertia force.

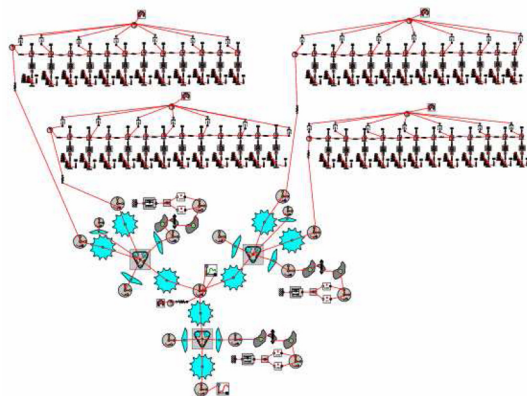


Figure 3. Complete rotational dynamics model (concept model)

Figure 4 shows the model elements in the primary reduction drive from the crankshaft sprocket to the intermediate sprocket. For the concept model the crankshaft sprocket was excited using data generated by a frequency domain torsional model of the crankshaft rotational dynamics (see Figure 5). For the correlated model the actual measured crankshaft sprocket motion was used as the input at the crankshaft sprocket instead of the calculated data.

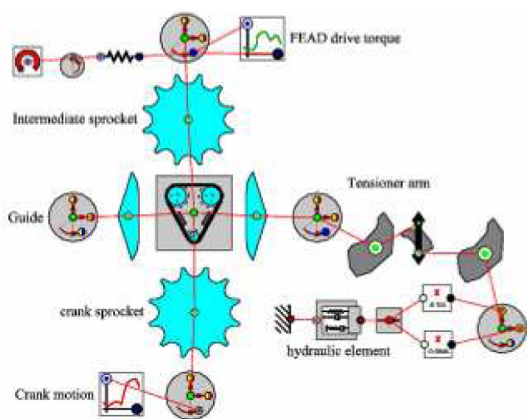


Figure 4. VALDYN model of primary reduction drive

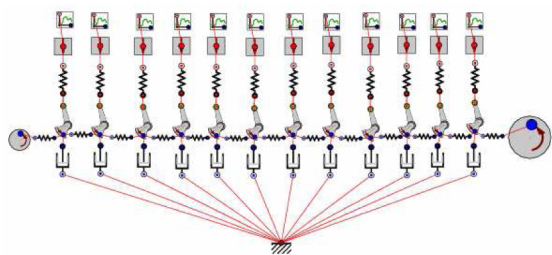


Figure 5. Model of V12 engine crankshaft

The sprocket tooth geometry was generated from the dimensions on the drawings. The chain drive model element required geometric data for the chain (number of links, pitch, pin diameter etc), mass properties (mass and inertia of each link) and stiffness and damping values for the chain and the chain/sprocket contacts. The chain data (geometry and stiffness) was provided by the supplier and a typical damping value was based on previous experience. The fixed chain guide model required the guide profile (taken from the drawings) and stiffness and damping values for the chain/guide contact (based on experience). Each tensioner was modeled as a pivoted rigid blade and a hydraulic element. The blade profile was taken from the drawings and chain/blade contact stiffness and damping values were based on experience. Each hydraulic tensioner was modeled as a moving piston mass connected to the engine structure by a spring and a hydraulic element (detailed internal dimensions were provided by the supplier). Other input data such as oil aeration level and damping were based on experience. Similar models were made for the other chain drives.

For the concept model the FEAD was modeled crudely as a single value of damping, applied at the primary reduction sprocket, and the torque to drive the loaded alternator referred to the intermediate sprocket. The damping was assumed to be low level in the hope that the actual sprocket motions and chain forces would be lower than those predicted at the concept design stage.

Each camshaft (see Figure 6) was modeled as a series of lumped inertia elements at the cam lobes and sprockets connected by torsional stiffness/damping elements. Each valve was modeled as a mass (which included the mass of the valve and the spring retainer). Each valve spring (2 per valve) was modeled by a series of mass elements (4 per coil) connected by stiffness elements. The valve spring data was taken from drawings. The hydraulic lash adjusters were modeled using a special element which included the effects of the expansion spring, hydraulic pressure, damping, leakdown rate, piston mass etc. Relevant data were provided by the supplier. Each tappet body was modeled as a simple mass element. Values of contact stiffness and damping were applied between the cam and tappet and between the valve and seat based on experience. The phasing of each camshaft was variable depending on the demanded phaser position. Each phaser was modeled as a pair of inertia values connected by a stiffness/damping element.phasers can be modeled using VALDYN in a more complete manner, including the influence of the hydraulic circuit and the control algorithm, but in the exercise a simplified approach was used even for the correlated model.