

# Optimized Engine Accessory Drive Resulting in Vehicle FE Improvement

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## ABSTRACT

A belt driven Front End Accessory Drive (FEAD) is used to efficiently supply power to accessory components on automotive engines. The total energy absorbed by the FEAD consists of the accessory component requirements, the belt deformation and friction losses as well as the bearing losses. The accessory component torque requirements provide accessory function such as air conditioning, fluid pumping and electrical power generation. Alternatively, belt related torque losses are a significant parasitic loss, since they do not contribute any useful work.

This paper will explain the source of energy loss in FEADs and outline a comprehensive strategy to reduce it. Test results comparing the effect of reduced friction on fuel consumption will be presented as well.

## INTRODUCTION

An automotive FEAD typically consists of an arrangement of components (A/C compressor, alternator, PAS pump, etc.) driven from the crankshaft by a rubber belt. An automatic belt tensioner is usually employed to provide static tension control, accommodate belt stretch and influence system dynamic performance through its damping behavior.

FEAD systems are faced with complex dynamic operating conditions. Torsional vibrations are transmitted from the engine, via the crankshaft pulley to the accessory component pulleys by a poly-v belt. This arrangement causes a rapid acceleration and deceleration of the belt, in line with the engine combustion cycles. The accessory component inertias

represent a resistance to this motion, the response of which is a function of the belt mechanical properties along with the automatic belt tensioner characteristics, which together act as a spring/mass/damper system.

At some point in the engine operating speed range, one accessory, or a combination of them, may be excited into a torsional resonant response. Most FEAD systems exhibit two resonant frequencies of interest. The first system natural frequency is usually the alternator, since it typically has the largest polar moment of inertia (i.e. including pulley ratio to crankshaft).

During these resonant conditions, the component will undergo magnified torsional displacement. This effect can be moderated somewhat depending on the belt and tensioner characteristics; however, the local belt tension will fluctuate at a magnified level. The belt tension fluctuation will result in slip at the belt/pulley interface, as the local tension level approaches zero. At the same time, both the belt and component bearings can experience undesirable high loads as the instantaneous tension level reaches its peak value. In order to avoid belt slip during these resonant conditions, the static belt tension is usually increased such that the instantaneous tension never approaches zero.

FEAD resonance can manifest itself in different ways:

- High tension and damping requirements or increased tensioner arm motion
- Belt rumble and/or slip noise when high accessory torques exist
- High sensitivity to belt misalignment
- Reduced belt and/or bearing life
- Increased engine drive (or friction) torque

As a result of the dynamic tension fluctuation that occurs during resonance, many FEAD systems are 'over tensioned' in order to avoid this belt slip issue.

Vibration isolation devices employed in a FEAD system optimization approach can reduce engine torque requirements, causing both an increase in fuel economy along with a corresponding drop in emissions. As explained above, NVH as well as durability will be improved as well through this tension reduction approach.

## RECENT HISTORY OF THE FEAD

Prior to 1979, automotive FEADs were typically driven by v-belts that were tensioned by manually adjusting the position of one of the accessory components. The basic principal behind this approach was to set the initial tension high enough, such that during the anticipated life of the belt, the tension would decay, but remain above the minimum tension required to drive each and every component, during all operating conditions.

In 1979, Litens Automotive Group introduced the first automatic tensioner, in combination with the first poly-v belt, on the Ford Mustang. This mechanism was in effect, a sprung free spinning pulley. It was located as the last component in the system, thereby setting the minimum tension for the system, when the crankshaft was driving the components as shown in Fig. 1.

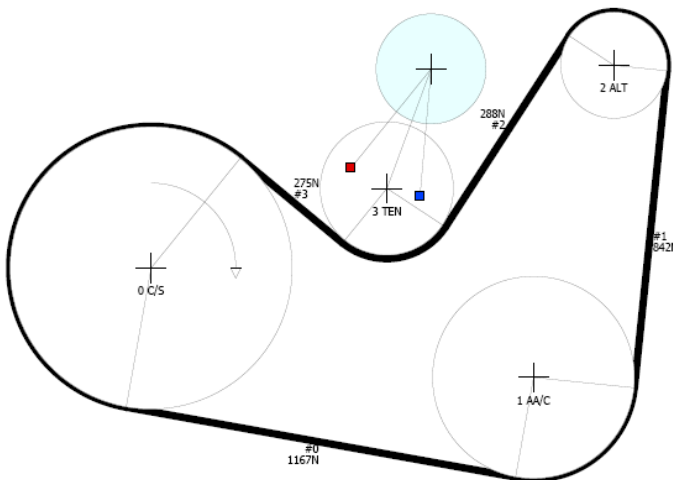


Fig. 1: FEAD Schematic indicating Static Tension Levels

Automatic tensioners represented an improvement over statically tensioned v-belts since they provided the possibility of a known average tension range that could be controlled for the life of the belt. In addition, the poly-V belt had a much thinner cross-section, resulting in (among other attributes) improved belt life.

Static factors that FEAD tensioners have accommodated for are:

- FEAD positional build tolerances
- Permanent belt stretch and wear
- Belt length tolerance
- Thermal expansions of the engine/belt

Furthermore, when the tensioner damping and static tension level has been tuned properly, and the FEAD does not exhibit a strong resonance within the engine operating range, it can be effective in maintaining dynamic system tension levels as well.

Dynamic factors that can often be compensated for are:

- Transient component torque changes (i.e. A/C clutch engagement, P/S lock, etc.)
- Crankshaft torsional input to the system and its corresponding response with component inertias

Unfortunately, the tensioner, along with the rest of the FEAD, appears to be one of the last priorities when new engines are being designed or upgraded. In addition, the torque requirements and inertia for the driven accessory components have increased substantially from the past, along with there being a higher crankshaft input with modern engines. As a result of these changes, many limiting design constraints have been placed on these systems, resulting in poor system tension characteristics and NVH caused by belt flutter and misalignment, as well as excessive tensioner arm motion.

A more recent trend has been to utilize very low modulus belts (aka 'Stretchy') in place of automatically tensioned drives, in an apparent effort to reduce component cost and improve packaging. Unfortunately, one of the typical disadvantages with these systems is substantially increased static and dynamic tension/hubload fluctuation.

These common symptoms can manifest themselves in the form of:

- Increased NVH from:
  - Belt flutter
  - Misalignment noise from higher static and dynamic tension
- Component bearing failure due to higher hubloads
- Component mounting bracket failure due to higher dynamic hubloads
- Increased fuel consumption due to higher static and dynamic tension levels

The intent of this paper is to inform the reader of a relatively new system design approach for FEAD that will facilitate historically low system tension levels realizing:

- Reduced system weight
- Increased packageability (narrower belt/pulley width and smaller component bearings and structures)
- Substantially improved system dynamics
- FE improvement/emissions reduction

## FEAD OPTIMIZATION FOR FE IMPROVEMENT

Initial development work conducted by Litens related to parasitic torque reduction, focused on component bearing losses that could be reduced through tension reduction. This development work concluded that these losses are normally very small in magnitude, except when tension levels are very high. Shortly after this conclusion had been reached, an OEM informed Litens that they realized a 2% FE improvement, after testing an optimized FEAD, which included a torsional isolator for the alternator that allowed for a 200N tension reduction.

Research was initiated into better understanding the variables associated with friction losses in belt drives. The outcome of this effort was that accessory belt deformation and belt micro-slip are typically the main contributors to parasitic loss in FEAD systems. It was also determined that independent losses occur in both a dynamic and static sense.

The static belt deformation loss mechanisms can be categorized as follows:

### BENDING:

Energy is dissipated when the belt bends, as it starts to engage a pulley, and follow its radius of curvature. Since the belt is not a perfect spring, this energy is lost both on the entry and exit of each pulley.

The elements that will decrease the torque loss through this mode are:

- Larger pulley diameter
- Reduce belt bending stiffness

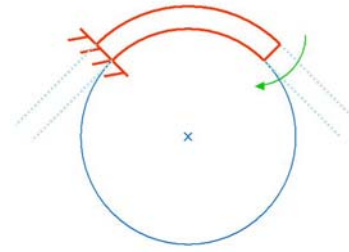


Fig. 2: Schematic of Belt Bending Loss

### RADIAL COMPRESSION:

When the belt makes contact with a given pulley, the tension present in the engaged section of belt compresses it along a radial path, centered at the given pulley origin. As with the bending mode mentioned above, the energy loss occurs both at the point of entry and exit (with the pulley) of the belt.

Variables that can reduce this energy loss are:

- Reduce tension
- Reduce component torque draw
- Increase radial stiffness

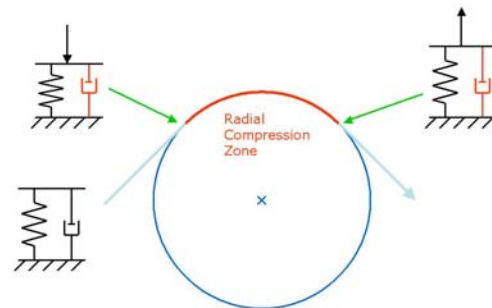


Fig. 3: Schematic of Belt Radial Compression Loss

### STRETCHING:

As a component pulley transmits a resistance torque to the FEAD, through the belt, the local belt tension level (across the arc of contact) changes accordingly. This tension gradient will cause a corresponding change in the local strain of the belt.

Factors that will decrease the torque loss through this mode are:

- Increase tensile belt modulus
- Reduce belt tension