A TRIZ SOLUTION FOR THE ACCESSORY DRIVE OF INTERNAL COMBUSTION ENGINES*

Eugene Rivin

Introduction

An internal combustion engine provides all of the energy requirements in both surface and marine vehicles. These energy demands go far beyond the engine's primary function, which is to satisfy a vehicle's propulsion needs. The most common vehicle – a passenger car – has a powerful air conditioner, and up to 40 electric motors used in everything from assisted power steering to automatically adjustable seats to retractable roofs in convertibles. These so-called "accessories" are powered by the same engine that runs the car.

While the typical power capacity of internal combustion engines, installed in nearly all cars, ranges between 100-300 HP, most of that power is used only during rapid acceleration. As a proportion of total capacity, the power output required for the operation of accessory drives in a car is small, totaling about 3-6 HP. Yet when viewed in light of the 6-12 HP required for the propulsion of a car at cruising speed, accessory drives consume an extraordinarily high amount of power.

Practically all cars have their accessories set in motion by the crankshaft via a serpentine belt drive consisting of one or two belts (see Figure 1). The belts come in contact with several pulleys, both active and tensioning ones. The constant bending and stretching of the belts, together with an engine running at high speeds, often as much as 8,000 rpm, precludes the use of V-belts in accessory drive systems. Universally, low profile poly-V belts are used in these applications.

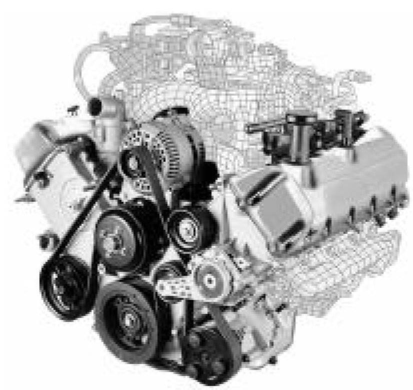

Fig. 1.

System Conflicts

The required outputs of accessory drives either do not depend on engine (crankshaft) speed (e.g., the air-conditioner), or are highest at idle (the lowest) speed, such as output from the power steering pump. However, since the majority of commercially available vehicles usually have constant transmission ratios between the crankshaft and the accessories, the variation of engine speed between 400-800 rpm (idle speed) and 2,000-5,000 rpm (cruising speed), results in an

---

* Presented at *the 3rd International Symposium on Total Product Development,* Dearborn, Michigan, October 5, 1997.

equally wide range of speed variation among the accessories. Consequently, accessory drives operate at extremely high velocity ranges during a vehicle's cruising speed (as much as 20,000-25,000 rpm).

Every accessory unit has a relatively narrow range of rpm within which its energy efficiency is at its maximum, and all accessories have bearings whose energy losses mount rather quickly at high rpm. Therefore, the operation of accessory units throughout the broadly varying speed range, especially at very high rpm, results in a significant amount of wasted energy. There are several estimates showing that this waste amounts to a reduction of overall fuel efficiency in a car by 0.6-0.9 miles per gallon. In addition to the significant energy losses, unnecessarily high speed rotation of the accessories, generates objectionably high noise levels (especially, for alternators) and reduces the lifespan of common bearings, forcing designers to use more expensive bearings made for high speed applications.

The productivity of each accessory unit depends directly on its size and rpm capacity. The critical range is at idle speed, because accessories maintain their lowest rpm at this regime. Usually, there is an accelerating transmission ratio between the crankshaft and the accessories. With a fixed transmission ratio, performance of the alternator might be inadequate at idle if the battery is low. In such situations, the Electronic Engine Control unit (EEC) increases engine rpm output, resolving the problem, but this event creates an increase in engine energy loses. To alleviate the problem, the size of accessory units could be reduced if their rpms at idle were increased. However, increasing the transmission ratio would result in even greater and unacceptable rpms of the accessory units at high engine speeds.

The TRIZ Approach

There is a definite system conflict in this situation. On one hand, the transmission ratio between the crankshaft and the accessories should not be too high – that is, in order to reduce energy losses, abate noise and improve the operating environment surrounding the bearings. On the other hand, the transmission ratio should be high in order to provide for adequate outputs of all the accessories at idle and, further, to reduce their size and weight. TRIZ suggests the following three generic approaches for completely resolving all competing requirements:

- separation of the contradictory properties in time;
- separation of the contradictory properties in space;
- separation of the contradictory properties between the system and its components.

It appears that the two latter approaches cannot be applied in this case. Application of the first, however, suggests that the transmission ratio should be high at low engine rpm, such as at idle, and low at high engine rpm, such as during rapid acceleration. In other words, this situation can be reformulated as a design conflict, and resolved with known TRIZ principles

Unfortunately, it is impossible to obtain a solution with the conventional poly-V belt transmission. There are no known designs for variable transmission ratio poly-V belt transmissions. The only commercially available variable transmission ratio belt drives, are drives using V-belts in conjunction with adjustable-width pulleys. There are also patents, dated as far back as 1901, on variable transmission ratio belt drives using segmented pulleys with adjustable radial positioning of the segments.

An analytical comparison of these variable transmission ratio belt drives has been performed, and two prototypes of the flat belt drives were fabricated. Neither of these turned out suitable for the accessory drive system. As for the variable transmission ratio V-belt drive, while it satisfies the need for the ratio adjustment in the required range, it cannot be used for the multi-pulley drive system due to its inadequate fatigue life. At the same time, while the fatigue life of flat belts is adequate, variable diameter pulleys are exceptionally heavy and not adequately reliable because of the large number of segments they employ.

One of the Laws of Technological System Evolution, which represent the cornerstone of TRIZ, is the Law of Transition to a Higher-Level System. It states that when systems exhaust their performance potential, combining two or more systems into a higher-level system (a "super-system") may result in a significant performance enhancement.

Application of this Law was ultimately the impetus for developing a combined V-belt/flat belt variable transmission ratio drive for engine accessories. In this system, the V-belt is used to provide for the required variable transmission ratios while the flat (or poly-V, or timing) belt drives most of the accessories (see Figure 2).

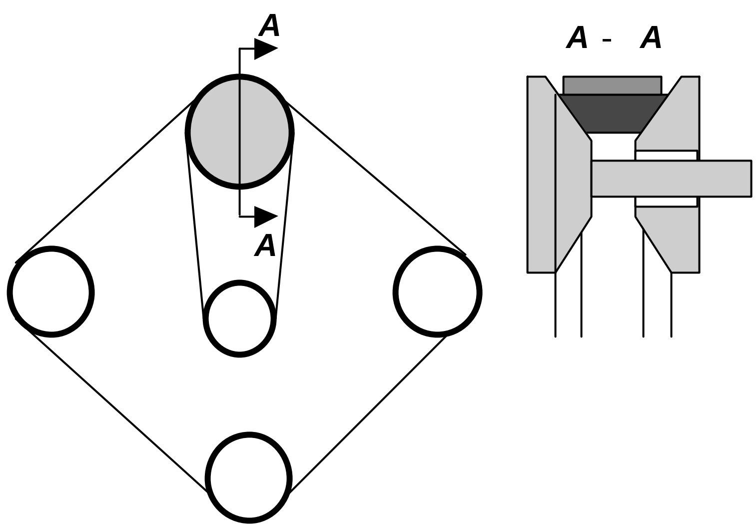

Fig. 2.

The design in Fig. 2 represents a model where the accessories maintain a constant speed, regardless of crankshaft speed. In this design the V-belt has a long fatigue life because repeated bending is avoided. This design also reveals that even in the case of the most demanding power accessory (e.g., alternator) driven directly by the V-belt, the flat/poly-V belt can be made thinner, hence further improving performance of the overall system.