Product Innovation Program in the Field of Flexible Components for Automotive Suspension Systems

Pacifico Marcello Pelagagge
Faculty of Engineering, University of L'Aquila
67040 Monteluco, L'Aquila, Italy

Abstract- *The paper presents results of a pilot project on technological innovation of main flexible components for automotive suspension systems, that are coil springs and stabilizer bars. Current technology has been described and related problems have been outlined. In order to fulfil features as compactness, lightness and environmentally conscious design, solutions based on new forms, materials and manufacturing processes have been proposed. Improvements in weights, dimensions, noiselessness, corrosion and fatigue strength, environmental effects, have been all assessed, keeping a quite low project cost (around $ 3 million).*

Keywords: Automotive Suspension Components, Product Development, Innovation Program, Design for Environment

Introduction

In a highly competitive and turbulent market, products have to be continuously innovated taking especially into account performance, quality, cost and environmental aspects [1]. From this point of view, components for automotive industry appear as critical products asking for increasing technological levels in order to compete in the present global context [2,3].

Bearing this in mind, an University-Industry joint educational program has been undertaken aimed to product innovation in the field of flexible components for automotive suspension systems [4,5]. The program involves a big company in operation since the 1885s that is today characterized by 7 plants in three European countries with a workforce of more than 1000 employees. The company supplies original components (relevant products are coil springs, leaf springs, stabilizer bars, etc.) to the most important worldwide manufacturers of cars and industrial vehicles. The constant technological updating of plants, automation and control of production processes are consolidated activities of the company, but the objective is also to continue to improve for an increasingly better and more competitive products.

With this aim, a product innovation study has been started taking as reference for pilot development both coil springs and stabilizer bars, which represent main components in actual automotive suspension systems.

In the paper a detailed analysis of the various problems in the present product technology has been preliminarily carried out. Most important limits may be summarized as:

for coil springs

- tendency to amplify sound vibrations arising from coil impacts
- low corrosion protection
- high weights
- relevant overall dimensions
- reduced fatigue strength

for stabilizer bars

- strong constraints around the rotation fulcrum
- compliance of the journal box due to material dishomogeneity
- slipping between bar and journal box give rise to noise starting
- using metal in journal box increases the overall system weight
- goal of ecological product is hampered by material dishomogeneity
- production process appears as complex and expensive
- high weight of solid bars

Solutions to overcome actual limits have been then proposed and analyzed considering a cost-quality- safety-environmental overall perspective [6-9], that are:

for coil springs

- new form able to reduce weights and dimensions, also avoiding impacts between end coils
- thermoplastic coating which allows for both noise damping and corrosion protection
- new materials, i.e. titanium alloy, to improve performances
- redesigned processes for heat treating to pursue higher fatigue strength

for stabilizer bars

- tubular materials for bars
- thermoplastic materials for all the journal box

Product design patents have been already applied for both the form and thermoplastic coating of coil springs and for the entire thermoplastic journal box.

Integration of innovated products with manufacturing processes has been also illustrated. Finally, the costs and benefits arising from introduction of new coil springs and stabilizer bars are discussed and the overall consistency of the project is checked.

Main Problems in Actual Product Technology
Coil Springs (figure 1)

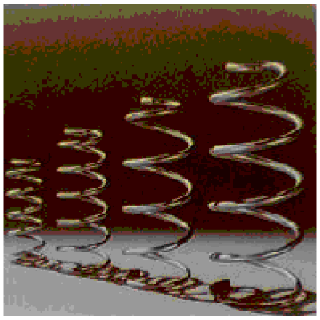

Figure 1 - Coil Springs

Continuous refinements in internal combustion engines together with improvement and extension of the road network allow for potentially higher and higher car utilization speed, giving rise to a wide spread of independent wheel suspensions in place of traditional rigid axle with leaf springs. Such successful achievement of independent wheel systems arises from better safety performances in terms of adhesion in different ground, route and speed states. Therefore, actual suspension systems adopted by automotive manufacturers use coil springs dedicated to each wheel, mainly performing as vehicle frame supporter guaranteeing at the same time driving stability and safety.

Coil spring bottom and top end locations are respectively close to the wheel hub and the vehicle frame. Spring supports are usually made of stamped plates following the end coil shape (figure 2).

Figure 2 - Spring Supports

The increasing of car performances causes new technological problems connected on the one hand to structural aspects, on the other hand to available space and overall dimensions constraints towards other suspension and body members. As a consequence, coil springs present some critical factors that may be briefly indicated as:

- coil-coil and coil-support impacts,
- reduced corrosion strength.

Impacts, in particular, give rise to sound vibrations which are greatly amplified by chemical-physical properties of the harmonic spring steel. These problems have been partly solved in current technology by adding plastic elements on coils of the spring and by resorting to paints for the corrosion protection.

Further remarks are moreover required by the bottom end shape of the coil spring, appearing unsuited to the increased performance that actual suspension systems ask for. In fact, if the coil spring top ends with a *curl* (figure 3), this is not present at bottom end due to insurmountable design and technological difficulties so far.

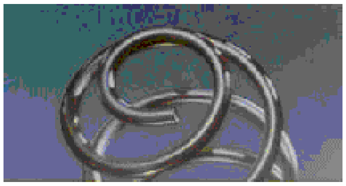

Figure 3 - Top End Curl

That is, the bottom end shape has to be cylindrical anyhow for both conical and cylindrical springs (figure 4).

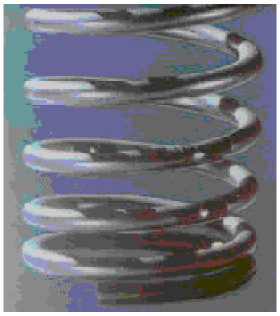

Figure 4 - Bottom End Shape

For instance, a main point hampering to create a bottom end curl emerges when the need to allow the spring sliping out of a mandrel after the hot winding process has been taken into account.

As a matter of fact, the bottom end shape of actual springs introduces inactive coils which uselessly enhance weights and overall dimensions of suspension systems, besides increasing support surface and noise primer probability.

Finally, other problems linked to current production technology mainly arise from the critical phase of round bar heating. As coil springs are usually manufactured starting from an alloy of carbon steel (55-60%), silicon (1-1.7%), manganese and chromium, decarburization phenomena very likely occur, also favoured by silicon solubility inside the iron matrix. As well known, decarburization consists in carbon partial removal due to oxygen reactions producing monoxide initially and carbon dioxide after. In practice, weak ferritic spots on outer surfaces of the round bar strongly grow up above 750°C. Just such surfaces then suffer the maximum torsional stress in coil spring hot winning (figure 5), therefore increasing the risk of premature fractures.

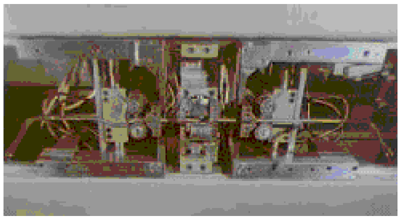

Figure 5 - Coil Spring Hot Winning

After all, reduced fatigue strength results, due to the crystalline matrix weakness. Operating parameters greatly affecting decarburization phenomena are the oxygen content and the rod stay time at the highest heating temperature.

To sum up, main problems in actual coil spring technology are:

- coil impacts,
- low corrosion protection,
- high weights,
- relevant overall dimensions,
- reduced fatigue strength.

Stabilizer Bars (figure 6)

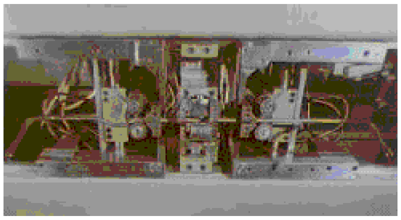

Figure 6 - Stabilizer Bars

Likewise coil springs, stabilizer bars are one of basic components in independent wheel suspension systems acting when car accelerations happen. In particular, stabilizer bars improve the driving safety and the ground adhesion, above all in rolling conditions and in curve braking. In these situations, front and rear stabilizer bars perform a load balancing between wheels. So, stabilizer bars work as self-governing devices when accelerations modify the center of gravity position, giving rise to dangerous instabilities. Furthermore, rolling instabilities considerably worsen the ride comfort. From this point of view, usual design criteria impose an upper bound of 4° for the rolling angle. According to this hypothesis, the coil spring flexibility may be firstly evaluated depending on the load and on the wheel amplitude runout between bump and bounce. Successively, the necessary flexibility of the stabilizer bar is determined which cooperating with coil springs guarantee the specified rolling reduction.

Stabilizer bars are placed transversely to the wheel axis, both in front and rear sides. Solid section bars have been normally employed in order to reduce raw material costs, however making the overall system heavier. A trapezoid shape is adopted for stabilizer bars where the lateral branches join together wheel hubs, whereas the remaining side carries out the task of support on the frame cross member. During the wheel push-pull rebound, bar longitudinal branches work as crank arms with rotation fulcrum on the transverse branch.

In usual engineering practice the fulcrum is composed of two journal boxes allowing for both rotations and small lateral movements (figure 7).

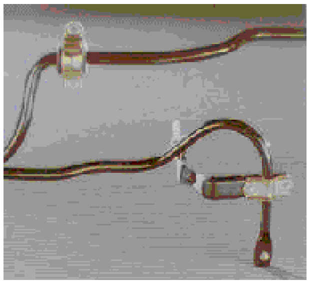

Figure 7 - Journal Box

Present journal box is made of plastic and metal components. In particular, the former is a support bushing with a minimum of elasticity, the latter is the link element with the vehicle frame. The assembly of journal box components on stabilizer bars is carried out directly from flexible system manufacturers by resorting to prevalently manual special workstations (figure 8).

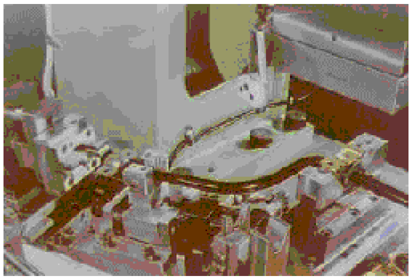

Figure 8 - Assembly Workstation

Stabilizer bars fitted with accessories, in fact, are required by automotive industries ready for final robotized installation on car frame.

As a result, some problems characterize current product technology mostly arising from material dishomogeneity in journal box:

- strong constraints around the rotation fulcrum,
- compliance of the journal box,
- slipping between bar and journal box give rise to noise starting,

- metal in journal box increases the overall system weight,
- goal of ecological product is hampered,
- production process appears as complex and expensive,
- high weight of solid bars.

Technology Innovation Program

In order to try removing the previous described problems, a product innovation program has been developed based on different technological concepts following illustrated.

Coil Springs

Solutions based on innovative coil spring form with bottom end curl, thermoplastic coating, high performance materials, controlled atmosphere furnaces, have been proposed and analyzed.

Coil Springs with Bottom End Curl

Development of coil springs with both top and bottom ending with a curl determines a significant step towards suspension system optimization. In this way a better use of the spring may be pursued thanks to inactive coil absence, also reducing weights and overall dimensions. Furthermore, impacts between end coils are avoided decreasing noise probability.

Having this in mind, the innovation program has been aimed to solve geometrical and structural difficulties, the latter also affected by the production process. In detail, the shape of the bottom end curl defines support plate characteristics close to the wheel hub. Therefore, the curl exact location determines the constraint reaction resulting vector. Being the coil spring usually assembled on the shock absorber directly, thrusts with normal direction respect to the shock absorber axis may be arisen from an incorrect reaction position. As a result, the seal of the stem may be damaged by those thrusts. In order to correctly positioning the constraint reaction, the curl initial pitch, eccentricity and diameter, simultaneously have to be strictly controlled.

An other critical aspect concerns the coil spring bedding requiring a package compression. The permanent deformation during this operation may determine unwelcome coil spring geometrical variations.

The innovated coil spring has been in detail designed also defining starting pitch, rotation angle, axial shifting, grip points on cylindrical body, and more. Furthermore, present production process has been integrated with a latter hot phase for bottom end curl manufacturing (figure 9).

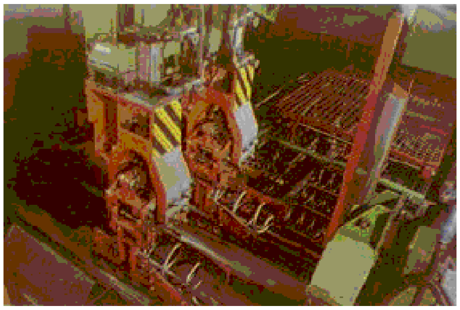

Figure 9 - Manufacturing System

Robots pick up the spring from the winning cylindrical mandrel, putting then in place on a particular plate. The plate is equipped with a gripper able to perform a further 360° rotation along a conical trajectory.

The double curl coil spring manufacturing process being extended, longer rod heating times should be required, giving nevertheless rise to unacceptable decarburization phenomena. In order to overcome this obstacle, a controlled atmosphere furnace has been adopted also increasing of about 10% resulting fatigue strength. The maximum oxygen content has to be continuously feedback controlled with the aim to obtain a constant dew point at the operating temperature. That is, an adjusted flow of inert gases mixed with gaseous fuel have been fed to the fully airtight furnace.

Thermoplastic Coating

If double curl springs avoid noise arising from end coils, sound vibrations from impacts between spring and supports cannot be prevented. Thermoplastic coating covers all the coil spring as a sheath.

This innovative proposal allows for noise damping and at the same time for higher corrosion protection. From this latter point of view, traditional spring painting for 300 hours at best protects. The next thermoplastic layer may increase corrosion protection up to 1000 hours. Such a solution, other than resolving corrosion problems, makes rubber on plates and PVC tube on coils not more required. Benefits clearly emerge when difficulties in assembly noise protection elements have been taken into account.

Thermoplastic materials which seem to offer better acoustic performances are polyurethan and polypropylene resins. Laboratory tests point out a damping capability of about 6 DBA. The improvement may be noticed observing as halved noise achieves from only 3 DBA damping. The optimal thermoplastic thickness has been investigated in the range 0.3-0.8 mm.

A continuous production process has been developed which, starting from the cataphoresis painted springs, follows with heating, thermoplastic coating and final heat treating. The overall design involved the optimization of thermoplastic materials, thickness, heating temperature, coating process, and so on.

Titanium Coil Spring

Resorting to titanium alloy for coil spring production enables for significant weight reduction maintaining relevant elastic performances. For instance, an alloy Ti-3Al-8V-6Cr-4Zr-4Mo may have a 70% of titanium content, showing a density of 4500 kg/m^3 respect to 7500 kg/m^3 of traditional steel and an ultimate tensile stress of 150 kg/mm^2 respect to 24 kg/mm^2.

On the other hand, crystalline matrix aging may occur in titanium alloy. In spite of traditional spring steel, titanium alloy offers increased performances only after particular heat treating and exactly respecting long stay time at defined temperatures.

In the project, the material behaviour at permanent deformation temperatures has been characterized, also investigating crystalline changes able to performance improvements. Titanium coil spring manufacturing process may be carried out by hot winning for rod diameters greater than 10 mm, by cold bending for smaller rod diameters.

Being the titanium alloy costs much higher than traditional Si-Cr steel, only advanced applications have been considered, as concept car, special body car, etc.

Stabilizer Bars

With the aim to contribute solving previous illustrated problems, an innovative global solution based on entire thermoplastic journal box and tubular bars has been conceived. Such a solution allows for free rotation and lateral shifting, reduced compliance, noiselessness during slipping between bar and journal box. In this way a prompt action is assured able to guarantee the maximum load on wheels in every driving situation. Furthermore, the entire thermoplastic solution reduces the weight of the final product fitted with accessories, also simplifying the journal box assembly. Tubular materials for bars contribute to weight reduction too. Last, but not least, thermoplastic journal box represents an ecological product (eco-label) easy to recycle [10-12].

Thermoplastic Journal Box

The thermoplastic journal box is composed of three cooperating parts, that are:

1) rigid external support,
with inside
2) co-molded elastic material working as a bushing,
which couples with
3) plastic component co-molded on the bar.

Components 2 and 3 guarantee rotations and slipping. Connections between components have been obtained by some ratchet pawl.

Using entire thermoplastic journal box, benefits in terms of weights, noiselessness, environmental sustainability and simple assembly phases, are allowed.

Nevertheless, the wide variety of rear and front stabilizer bar geometrical shapes, together with the variability of both forces and frame architectures, ask for the development of effective design and manufacturing methodologies. So, the innovation program involved among other things component design optimization depending on space availability, stress distribution verification, performance experimental check.

As far as the production process is concerned, greatest difficulties arose really from material dishomogeneity of journal box. For instance, stamped plate prototypes were always complex to made and however they inadequately represented the final configuration. As a consequence, seaming press needed for long setup times by tests and simulations. Furthermore, the contact surface of metal component was not modificabile, strongly delaying definitive die manufacturing. Very advantageous approaches may be undertaken when all thermoplastic components are adopted. In particular, prototypes are simple and they strictly represent final products. Each component is indipentently manufactured and may be easily modified along the work cycle. Finally, the co-molding on the bar only requires the definition of devices for bar fixture.

Tubular Bars

Tubular bars are a specific market requirement aimed to suspension system weight reduction. As aforementioned, stabilizer bars only occasionally work when rolling or jaw occur, therefore appearing strategic to pursue weight economy and energy saving.

A pilot plant has been developed based on both hot forming and cold bending. In this way the steel performance may be improved by austempering and the weight-strength ratio optimized.

Cost-Effectiveness Analysis

Innovations of coil springs and stabilizer bars represent the first experimental development of a project dealing with competitiveness improvement in the field of automotive suspension systems. The fulfillment of features as compactness, lightness and environmentally conscious design, keeping at the same time high operational performances, leads towards deep modifications in product technologies [13]. With this purpose, new forms, materials and manufacturing processes have been surveyed and suggested. Although further refinement activities are required and some subsystems have not been completed yet, effectiveness of innovated products has been successfully assessed also through quite low-cost implementation.

Going into more detail, main costs of the product innovation program can be ascribed to following items:

- problem analysis, product design, process synthesis, machines improvement, installation and tests, have been carried out for the most part by corporate engineers and technicians, accounting for an overall cost of about $ 1 million;
- hardware investments in second curl manufacturing system, thermoplastic coating plant, molding machines,

molds, assembly equipment, controlled atmosphere furnace, complementary devices, giving rise to a cost around $ 2 million; and
- finally, around $ 0.25 million for advice and other accessory costs.

Effectiveness of the products obtained by the technological innovation programme may be quantified as follows:

for coil springs
- weight reduction 40%
- overall dimension saving 20%
- soundproofing improvement 70%
- corrosion strength increase 300%
- fatigue strength increase 15%
- productivity increase 10%

for stabilizer bars
- journal box weight reduction 30%
- bar weight reduction 35%
- soundproofing improvement 30%
- waste reduction 20%
- assembly time reduction 20%

The aggregation of previous achievements defines a comprehensive framework of the innovation, providing improvement of product technical efficiency, energy saving in complete life cycle [14-16], enhancement of operational safety, respecting official eco-labeling schemes intended to inform customers of environmentally friendly products. In particular, benefits from environmentally conscious design and manufacturing include safer and cleaner factory, worker protection, reduced future costs for disposal, decreased environmental risks, improved product quality at lower cost, better public image, and higher productivity.

As a result, skills of the innovative framework represent key factors for competing in the international market.

Conclusions

In the paper main results of a pilot project on product innovation have been presented in the field of flexible components for automotive suspension systems. In particular, methodological steps followed for design, development and experimental tests of both coil springs and stabilizer bars have been described. Most important innovative technical aspects concern double curl coil springs, thermoplastic materials use, production process integration.

First experimental results confirm starting expectations when the product innovation program was conceived, maintaining quite low project costs.

The proposed technological innovation, in fact, allows for flexible components characterized by peculiar performance, quality, safety, cost, environmental issues, increasing capabilities to compete in present global and turbulent markets. Nevertheless, product innovation programs represent a long term company goal that will require continuous improvements in critical topics as technology developments, management systems, cost models, and environmentally conscious design and manufacturing.

References

[1] Suh, N.P., Design and manufacturing of large complex product: the role of design and automation, *2nd Int. Conf. on Automation Technology*, 1992.

[2] Drejer, A., Frameworks for the management of technology: towards a contingent approach, *Technology Analysis & Strategic Management*, 1, 1996.

[3] Smith, P.G., Reinertsen, D.G., *Developing Products in Half the Time*, Van Nostrand Reinhold, New York, 1991.

[4] Calderini, M., Cantamessa, M., Innovation paths in product development: an empirical research, *Int. J. Production Economics*, 51, 1997.

[5] Sun, H., Patterns of organizational changes and technological innovations, *Int. J. Technol. Mgmt.*, 9, 2, 1994.

[6] Hundal, S.H., *Systematic Mechanical Designing: A Cost and Management Perspective*, ASME Press, New York, 1997.

[7] Peng, T.K., Trappey, A.J.C., CAD-Integrated engineering data management system for spring design, *Robotics & Computer Integrated Manufacturing*, 12, 3, 1996.

[8] Munoz, A., Sheng, P., Analysis of environmental impact for machining processes, *Int. J. Manufacturing Processing Technology*, 11, 1995.

[9] Whitmer, C.I., Olson, W.W., Sutherland, J.W., Methodology for including environment concerns in concurrent engineering, *Soc. Design and Process Science*, 1, 1995.

[10] Owen, J.V., Environmentally conscious manufacturing, *Manufacturing Engineering*, 10, 1993.

[11] Weissman, S.H., Sekutowski, J.C., Environmentally conscious manufacturing: a technology for the nineties, *AT&T Technical Journal*, 11, 1991.

[12] Bock, L., Material process selection methodology: design for manufacturing and cost using logic programming, *Cost Engineering*, 33, 5, 1991.

[13] Zhang, H.C., Kuo, T.C., Lu, H., Huang, S.H., Environmentally conscious design and manufacturing: a state of the art survey, *J. Manufacturing Systems*, 16, 5, 1997.

[14] Alting, L., Jorgensen, J., The life cycle concept as a basis for sustainable industrial production, *Annals of CIRP*, 42, 1, 1993.

[15] Ishii, K., Eubanks, F., Life cycle evaluationof mechanical systems, *Proc. NSF Design and Manufacturing Systems Conference*, 1, 1993.

[16] McCue, G., Life cycle engineering, *Management Service*, 2, 1993.