How the systems approach is determining automotive battery design and use

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Abstract

Today, the battery in a vehicle system is specific and designed as a single, stand-alone vehicle product. Traditionally, customer specifications were the driving force behind battery design and application requirements. This method is not able to comprehend the fluctuating requirements of real-time, vehicle systems. Growing competition in the automotive market is increasing customer needs and expectations in regards to cost, weight, size efficiency, time-to-market, and quality of the products and systems. System engineering is a service that Delco Remy, as an electrical power system supplier, offers to help their customers secure gains in the market place. System development and application engineering is essential for the development of performance-optimized components that meet the systems and total vehicle cost, reliability and timing objectives. The battery integration must be managed through the electrical power system during the complete vehicle development process in order to increase ultimately customer satisfaction.

The changing environment

As the automobile industry has developed, so have the methods and practices used in engineering the vehicle. From the beginning of the industry, it became common engineering practice to design all components for the vehicle at the vehicle manufacturer's engineering centre and then provide the finalized product specifications to component suppliers for manufacture. As the industry evolved, however, this relationship changed. Component suppliers began to assume more of the product design and specification responsability for the products. The component suppliers had core capabilities in specific products and technologies, while the vehicle manufactures had specific knowledge of applying the components to the vehicle. By working together on the design and application of the component, the vehicle manufacturers were able to obtain components that met the component requirements and specifications, but component-to-component interface issues and systems interaction problems were not typically addressed before hand. This arrangement, although more effective than previous approaches, did not always uncover problems until after vehicles had been sold to the end consumer.

Just as the relationship between automobile manufacturers and suppliers changed in previous decades, the industry faces a new need to change. The automobiles, that are presently produced around the world, have risen to such high levels of technology and sophistication that the current working relationship that has evolved between producers and suppliers may no longer be suitable for this environment. As more automobile companies focus their efforts on key strategic areas, the suppliers area is being asked to assume more of the application responsibility of their products. In

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addition, the rate of technological change and increasing governmental regulations have created the need for a new approach to designing, testing and building vehicles in an industry in which automobile manufacturers and suppliers must compete. This approach is the 'systems approach'.

What is the systems approach?

In its basic form, the systems approach is the result of a close cooperation between Delco Remy and their vehicle partners both during the complete vehicle development process and over the life of the vehicle. In comparison with past working relationships that were based on component focused issues, the systems approach that has been developed by Delco Remy concentrates on understanding the total interaction of the components and systems in the vehicle, the component and system specifications, the vehicle environment and other application specific factors that lead to proper integration of the 'electrical power system' (EPS) into the vehicle. The ultimate goal of the systems approach is to assure that the final vehicle customer receives a truly world-class vehicle.

The EPS on today's automobile is much more than the interaction between the vehicle's battery, starter and generator. Formally, it is a complex interaction of parts and subsystems that are designed to preserve the integrity of the starting system under a wide variety of driving situations and to provide power simultaneously for the increasing electrical content on today's vehicle. In addition to these tradition EPS functions, the system also encompasses electric propulsion, load management and energy conversion systems such as a heated wind-shield.

In order to properly design and apply the EPS, the engineering community must understand the environment of the system, the interactions with other vehicle components and systems, as well as how various driving situations and electrical usage profiles affect the system's reliability, durability and performance. Just as a surgeon must understand the interactions of the various organs and systems in the human body, automobile company and supplier engineers must have similar knowledge of the vehicles jointly produced for the end consumer. This level of understanding is only available by forming a long-term relationship based on teamwork between the supplier and the vehicle manufacturer, focused on system issues.

The fact that a single component is performing satisfactorily compared with its specification does not necessarily mean that the component will meet the vehicle system's performance, packaging, assembly, quality, cost and time-to-market requirements. The systems approach that has been developed assures that the integration of the components and subsystems into the vehicle achieves more than just meeting component specifications. The different steps of the systems approach (which is represented in Fig. 1) are:

- translation of customer's needs into requirements
- analysis to balance the requirements
- creation of design concepts from requirements
- evaluation studies and simulation to determine the design that best meets the requirements
- design definition
- development and validation of the components against the requirements

The systems approach can be thought of as an iterative process, Fig. 2, that consists of cycles of requirements, design and evaluation. Each cycle provides an ability to learn about the specific application being evaluated and to apply the knowledge

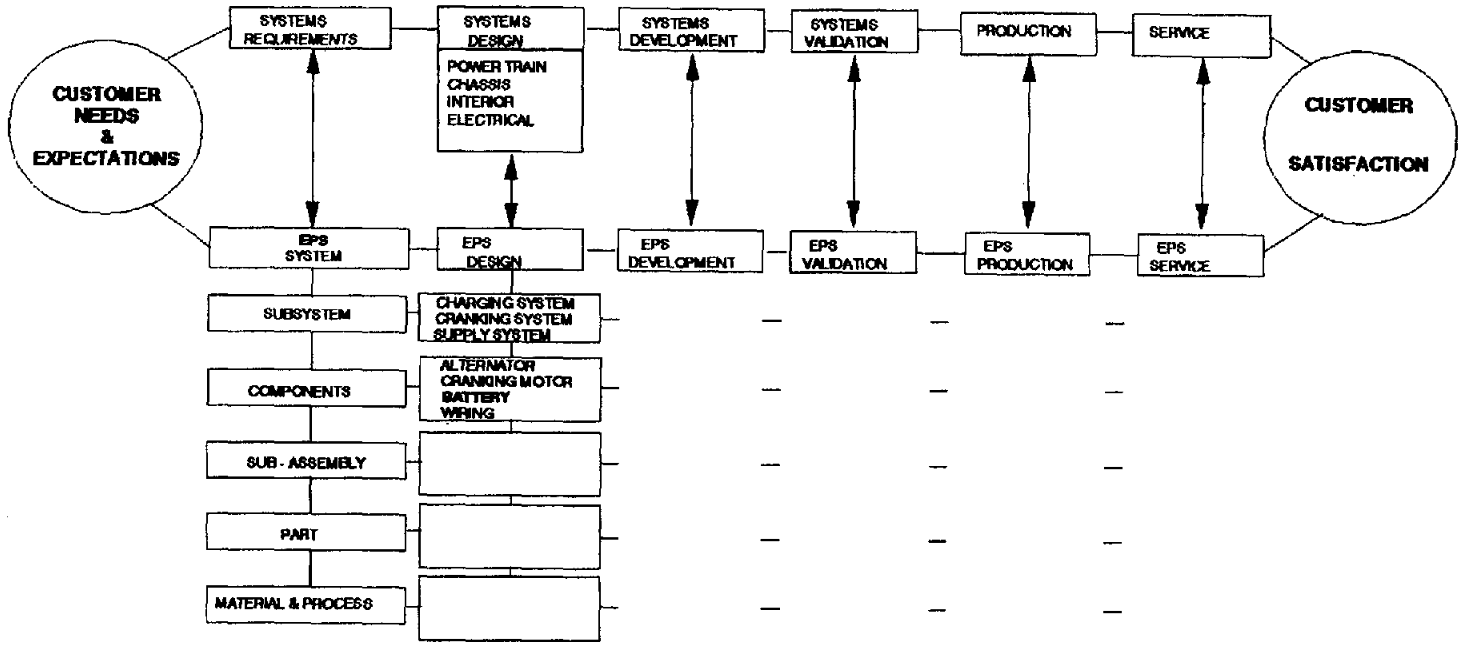

Fig. 1. The systems approach in vehicle development and manufacturing processing requires teamwork and systems understanding: design, development, manufacturing, quality, service and recycling.

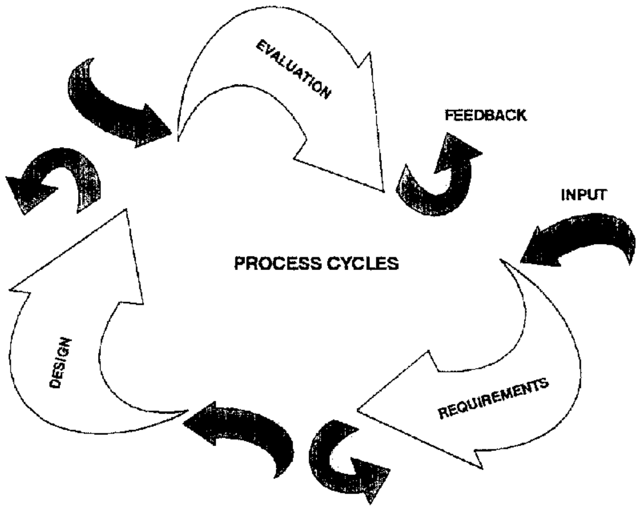

Fig. 2. Schematic showing the iterative nature of the systems approach.

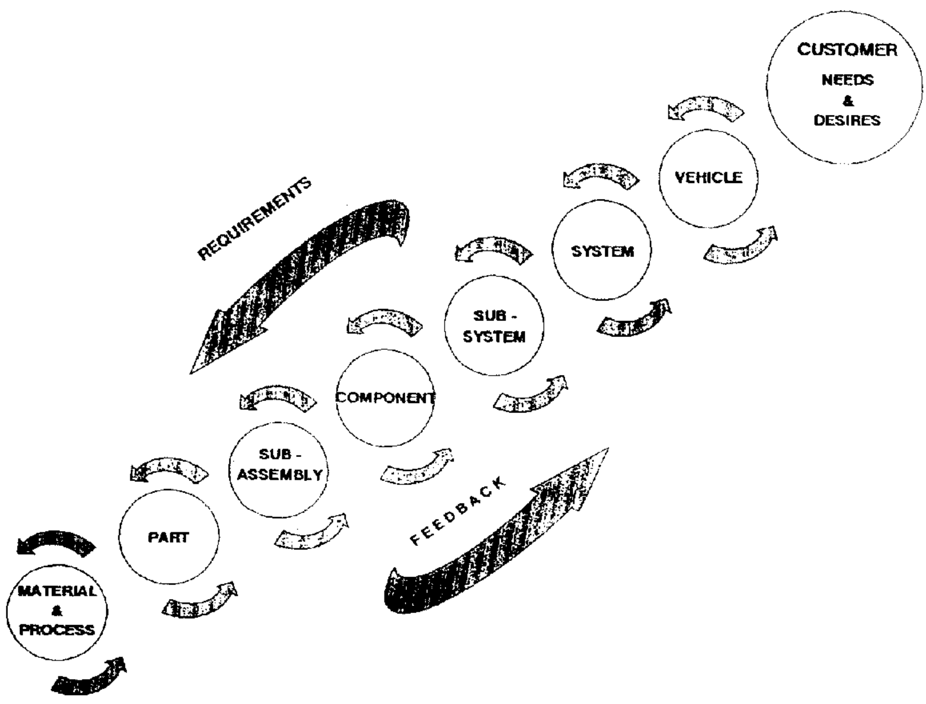

Fig. 3. Application of the iterative nature of the systems approach.

so gained during the next iteration. The benefit of this approach is that the learning is obtained from computer simulations and laboratory testing rather than from expensive on-vehicle testing. This allows Delco Remy and their partners to examine alternatives and designs before actual hardware is built and tested on the vehicle. Experience has shown that iterations and design changes made during these early stages of the process are orders of magnitude less expensive (in terms of time, money and other valuable resources) than similar changes implemented at a later phase.

The application of this iterative process results in controlling and predicting the impact of a change at any level of the process on systems, subsystems, components, subassemblies, parts, materials, and processes' performance and requirements, as shown in Fig. 3.

Needs to requirements

The first step in the systems approach is to fully understand, at an in-depth level, the customer needs that are driving the EPS component specifications and requirements. Unless the connection between the need and the requirement is understood, it is not possible to properly evaluate unique alternatives and options to satisfy the requirements that will lead to a sub-optimal design. As an example of this expanded way of thinking, a component specification may call for a product to have a splash-guard incorporated into the design. The true need of the system is, however, to have a product that can function for the life of the vehicle in a high-splash environment. If this is known up front, the product can be designed from the beginning to meet the high-splash environment in a more cost-effective manner than by adding a splash-shield after the fact.

Requirements to designs

Once the needs have been analysed and turned into requirements, it is necessary to commence the task of balancing these requirements to create the most effective design. Performance specifications, environmental issues (such as corrosion, vibration and temperature), packaging constraints in terms of weight and volume targets, and other areas are analysed to begin narrowing the design options. Tools such as 'quality function deployment' (QFD) are utilized to translate requirements into features and functions through the product-development process. From these analyses, several high-potential solutions can begin the evaluation process to determine those combinations that will meet both the needs and requirements in the most effective manner.

Evaluation through simulation

To evaluate properly which of the potential options best satisfies the vehicle system requirements, Delco Remy has developed several analytical tools that are utilized during this phase. Some of these tools are sophisticated computer programmes that give Delco Remy the ability to simulate any given vehicle in a multitude of driving and climatic conditions without the need for on-vehicle testing. The ability to perform such simulations has been developed through intense studies of actual driving schedules and real-world vehicle data. This information has been compiled and analysed for over two decades to correlate the computer simulation with actual customer experience. The simulation schedules are revised, as required, to reflect geographic and vehicle differences over time in order to maintain the most up-to-date simulation model in the world. These modelling techniques are extremely valuable in performing various "what if" scenarios and for evaluating a wide variety of system trade-offs. Additions to Delco Remy's simulation capability, such as the real-time analysis of vehicle systems, are currently being validated. These will provide an even greater knowledge of the complex interaction of the components, subsystems and systems that are being designed for the vehicles of tomorrow.

During this analysis phase, Delco Remy is able to evaluate the integrity of the EPS under a variety of electrical load situations that may be present on the vehicle during real-world driving conditions. By understanding the total vehicle system interactions, Delco Remy is able to determine the EPS combination that best satisfies all of the requirements.

Design development and validation

Now that an optimized EPS design has been developed, it is time to validate this design within the overall architecture of the vehicle. This is where the world of simulation meets the real world. As the design of the automobile has become more complex, so has the interactions between all of the systems on the vehicle.

As previously discussed, a component, subsystem or system that meets the proposed specification in the laboratory or on paper does not guarantee that the item will operate correctly on the vehicle or in the hands of the final customer. The primary goal must be to satisfy the ultimate person driving the vehicle, not just a specification. This is where a systems supplier can show tremendous benefit in the vehicle-development process.

By evaluating and understanding the interactions within the vehicle, the likelihood of system deficiencies and problems reaching the customer is greatly reduced. For example, at this stage, actual production-intent vehicle information such as underhood and component temperatures can be analyzed along with air-circulation and water-splash patterns to quantify the actual impact on the system's performance, reliability and durability.

Once this type of information is analysed and its implications understood, refinements to the systems or various action strategies, if required, can be implemented to reduce, or eliminate, the potential problem from the vehicle before it occurs. The past practice of focusing strictly on components' specifications does not always highlight potential vehicle systems problems until very late in the programme.

Support mechanisms

To provide the level of support that is required to undertake the above systems approach, Delco Remy has expanded its capabilities in the EPS area to span not only the entire vehicle-development process, but also the vehicle-manufacturing process as well as the service and recycling phases. In addition to the vehicle and components characterization tools and techniques discussed previously, Delco Remy has significantly added to its engineering facilities in Europe. The systems activity is centred at the ACG Technical Centre in Luxembourg. This location provides human resources, facilities and equipment for environmental, durability and vehicle tests in the analysis, application, design, development and validation of EPS components, subsystems and systems.

To further support the system focus, resident engineering groups have been strategically located to aid further in the design, application and production processes.

By colocating engineers at, or in, vehicle manufacturers' engineering centres, a much better understanding of the underlying customer needs and wants can be obtained. This leads to an increased understanding of the entire system.

As a systems supplier, Delco Remy also provides services for plant audits, warranty analyses and field testing when the system reaches the production phase. This support continues past the life of the system, as emphasis is also placed on engineering products that are environmentally correct and can be easily recycled and re-used in the next generation of systems.

Why is a systems approach needed today?

As with any change to the *status quo*, it takes time for various groups to (i) identify the need to change, (ii) accept the need for change, and (iii) embrace the change itself. As Delco Remy has used the systems approach for EPS, both customers and competitors have come to understand the need for changes in the way components are designed, integrated and validated on the vehicle. There are many factors driving the need for a systems approach to components in vehicular applications.

Laboratory testing, bench testing, product specifications and durability testing do not always accurately reflect the typical usage profile as observed on customer vehicles in the field. This particular issue can be seen today with lead–calcium battery technology, as many of the current test specifications are formulated with a constant-voltage recharge method. Significant field tests conducted around the world, as well as on-vehicle experience in approximately 200 million vehicles to date, have repeatedly shown that such a laboratory testing method does not correlate well with battery state-of-charge as measured in customer's vehicles.

Through a systems focus, with tools such as 'failure model effects analysis' (FMEA), systems integration can be understood at a broader level than through component and test specifications. Vehicle simulations and systems application work can specifically analyse critical interface, application and real-time conditions that are not considered during normal schedules for component testing. It is also not possible to test completely all critical areas via a component specification. Typically, this type of testing will also bring to the surface potential problems only after much of the product/vehicle design has been completed. Solutions to problems identified at this point in the testing are not resolved by redesigning the product to eliminate the problem, but by implementing a 'quick fix' solution.

Added to this concern is the fact that the present component specifications and requirements for EPS products are often based on past vehicle charging and starting systems' requirements. With the rapid growth in future electrical load requirements, changing engine performance characteristics, 'engine management systems' (EMS) and added vehicle complexity, future vehicle-system requirements cannot be interpolated from past requirements. Not only is the amount of content in future EPS systems increasing, but the rate of change of the technologies compared with the past is also increasing at a very rapid rate.

Many of the future components and subsystems that are contained within, or that interface with, the EPS are new products or technologies. Items such as high-power generation, multiple voltage systems, electric or hybrid vehicle systems and motor/alternator combinations will require a new and unique approach to development. The application of a group of optimized components together into a vehicle will most probably not result in an optimized system. It is only by looking at the larger systems issues, and then designing components and subsystems to meet these requirements, that an optimized system will be developed.

One of the current battles within the automobile industry is the focus on time-based competition. As vehicle manufacturers continually reduce cycle time for new product development, suppliers must also take steps to alter their development processes. During this same time, pressures within the automobile industry are forcing reductions in engineering resources. This will potentially shift more and larger responsibilities on to the supplier base. The combination of these factors will dictate a wider scope approach to vehicle component and system design development and application, with specific focus on time-to-market and vehicle-system knowledge issues.

Finally, another factor driving the systems approach is that of external forces. Government regulations regarding emissions levels, electromagnetic compatibility, pass-by noise and fuel economy standards will force changes in the way EPS components are designed. Trade-offs between individual component efficiency and performance versus overall systems efficiency and system performance can only be analysed at a system level. Past systems knowledge and experience will be critical in determining the optimal approach as existing vehicle systems are redesigned.

Systems approach with an increased scope

Although several aspects of the overall systems approach have been reviewed thus far, there are still many critical aspects of this approach that must be understood before an overall understanding can be obtained. One of those aspects is that of 'design for assembly' (DFA). A true system must not only meet the specifications of the release section or the test/validation engineering area, but also the manufacturing/process group's requirements. This means that mounting considerations and assembly tool requirements must also be understood by the supplier and incorporated into the design of the system.

A detailed understanding of these requirements can lead to the direct supply of totally-integrated system packages to the vehicle or engine assembly plant. By integrating separate components and subsystems into a single module, the assembly plant can reduce installation time, reduce the number of part numbers required and increase build quality, while the systems suppliers can better control the application, installation and integrity of their products.

Finally, this focus can lead to an in-depth knowledge of the serviceability issues of the system, as well as better understanding of issues associated with warranty analysis, reliability growth targets and customer issues at the auto dealerships's service department. It is evident that the systems approach as described must take into account the total life cycle of the product-development process, manufacturing process, after-sales support and, finally, recycling issues.

Benefits of the systems approach

As can be observed from the review thus far, the systems approach allows for weight, size, performance and cost optimized designs. Many examples at Delco Remy have been documented where a systems approach has led directly to significant benefits to vehicle manufacturers around the world. From a historical perspective, a systems approach was used by Delco Remy to bring to market the lead–calcium batteries that are currently used worldwide. This design focused not only on component specifications, but was developed with a systems focus in mind. Specifically, the benefits of lead–calcium batteries are a maintenance-free design for increased customer satisfaction, resistance to thermal runaway for application in today's higher under-hood temperature vehicles, low self-discharge for longer vehicle stand time, and resistance to overcharge for increased life.

More recently, Delco Remy has been able to reduce significantly the warranty rates and the system's cost on certain European and Japanese automobile manufacturer's vehicles through a complete vehicle electrical systems analysis. Because of the systems expertize that Delco Remy has developed over time, solutions to the systems' problems were found in a time and cost-effective manner that resulted in the elimination of critical problems without the need for the manufacturers to over design individual components. In one instance, the customer saved over 10 million FF.

In addition to the EPS focus, Delco Remy and the Automotive Components Group at the Technical Centre in Luxembourg have been concentrating on intersystems related issues. A programme for an EMS application provides an example. A cold-start problem that was initially thought to be related to engine calibration was analysed by a newly-developed EPS tool: 'engine performance analysis system' (EPAS). This system was able to pin point the problem as an issue not specifically related to the EMS. This system analysis saved an estimated 5 million FF in future development work that would have been required to correct the problem via engine calibration or a larger starting subsystem. The result was a vehicle with enhanced performance, increased startability, reduced product development time, and cost savings.

Another example of a systems approach that is currently still an on-going project is that of electric vehicles (EV). Performance, efficiency, packaging volume, weight, cost effectiveness, flexibility, range, safety, recycling, reliability, energy management and timing issues were just a few of the criteria used to design and develop the EPS for EVs. Delco Remy's EV system design is leading the world today because of the systems approach.

These examples, and many others are direct evidence of the benefits that Delco Remy can provide through its systems approach. Without this approach, none of these programmes or vehicles would have achieved the targeted levels of performance, timing, cost or satisfaction. The learning from the systems approach is a cumulative knowledge and is expanded as each new programme is added to the list of successful system achievements. In this way, Delco Remy and its partners can pro-actively focus efforts in the area of system problem avoidance, rather than consume scarce resources to fix a problem after it has occurred.

The future

Today's and future advanced engine designs, engine management systems, added electrical loads, higher power electrical loads, added electronic control systems, higher under-hood temperatures, mass saving objectives, environmental concerns, etc. are drastically changing the requirements of all components, subsystems and systems on the vehicle. Also, the vehicle-system requirements are dependent on the vehicle concept. Electric vehicles, hybrid propulsion systems or internal combustion engines will all drive their own unique sets of issues, requirements, specifications and problems. Future vehicle system architectures and linked vehicle networks, as envisioned under the PROMETHEUS project, will require new levels of thinking on the part of all team members who are involved in the life cycle of the vehicle. Suppliers to the automotive industry must create new designs and new engineering paradigms to match those of the vehicle and its future system's needs and technology. Vehicle manufacturers must also understand the implications of the change taking place in the automobile industry today. As part of this change, they must fully consider the components, subsystems and systems that make up the vehicle as an integral part of the total vehicle system.

In the future, suppliers to the automobile industry will not measure success solely on the number of components sold to automobile manufacturers, but will increasingly focus on the amount of learning that is obtained from the systems approach. As new designs are created that would never have surfaced, or as potential problems are eliminated prior to occurring because of the systems approach, the true benefit of this approach will gain a much wider acceptance. At this point, the ability to satisfy total customer requirements will be recognized.

Conclusions

In summary, it should be re-emphasized that quality, cost, responsiveness and customer satisfaction are the driving factors to the systems approach:

- quality because of optimized, improved designs with fewer changes and problems
- cost because of reduced prototypes, testing and tooling with fewer design and tooling changes
- responsiveness because of shorter design times and time-to-market issues

Everything leads to customer satisfaction. This is the primary objective of the systems approach.

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