NONDESTRUCTIVE TESTING ACTIVITIES, NEEDS, AND TRENDS IN THE AUTOMOTIVE INDUSTRY

G. Mozurkewich
Ford Motor Company, Research and Advanced Engineering, Dearborn, Michigan, USA

Abstract: Recent and ongoing NDT activities in the automotive industry are surveyed. Application areas include body structures, powertrain components, chassis components, and fuel systems. Examples are drawn from various NDT modalities but with an emphasis on ultrasonics. The business case for NDT and the manner in which it is applied are strongly influenced by the automotive sector's production volumes, cost structure, and consumer orientation. These aspects are compared and contrasted with the state of affairs in the aerospace and nuclear power industries. In addition, some attempt is made to forecast future automotive NDT needs and to project how current trends in NDT may be incorporated into automotive manufacture.

Introduction: A cursory perusal of NDT (non-destructive testing) conference proceedings usually uncovers little from the automotive sector. Programs are dominated by the nuclear power and aerospace industries, augmented by civil engineering and a few other fields. To appreciate this imbalance, it is worth contrasting the state of affairs in these industries.

Nuclear and aerospace involve large scale projects having long development and construction phases followed by even longer service lives. Public safety is a paramount concern, and catastrophic economic loss threatens. Consequently, these industries place great emphasis on attaining high operational safety and reliability and on maintaining them over decades-long service lives. Production volumes are small. A major commercial aircraft manufacturer may build and sell a few hundred units annually. The construction rate for new nuclear plants in the United States and Western Europe has dropped dramatically from a maximum of no more than a few per year. By their nature, aircraft require extremely lightweight construction, creating pressures to optimize use of materials and squeeze design margins. Irradiation-induced degradation in nuclear plants imposes unique materials complexities.

These considerations lead to the damage-tolerance concept in the air fleet and condition-based maintenance in nuclear plants. In the former, maximum permissible flaw sizes are established and elaborate programs are undertaken to ensure that flaws of that critical size can be detected with adequate confidence, both during production and in the field [1]. In the latter, key components are continuously or frequently monitored to detect deterioration [2]. While these inspection programs are expensive, the expense is defensible given the enormous financial investments and the spectacular costs of failures.

Circumstances in the automotive sector present a dramatic contrast. At any given time, a typical automobile manufacturer may be developing a dozen new vehicles and "freshening" a dozen more. In response to increasing market competition, new vehicles are developed in 36 months or less, sometimes much less. Production rarely continues for more than a few years before introducing major design changes. While some vehicles may remain in use by customers for more than a decade, factory warranties often expire after 3 years or 36,000 miles. (Certain emissions and safety components are warranted for considerably longer.) Despite the importance of crash worthiness as a design factor, most automotive systems and components have little direct relation to the vehicle's safety. Although the financial setback resulting from a major warranty recall can occasionally be staggering, catastrophic human and economic loss on the scale contemplated by planners in the nuclear industry is not a threat. While weight reduction has a favourable impact on fuel economy, the pressures driving lightweight construction are, compared to aircraft, relatively benign. Consequently, beyond obvious safety and quality matters, the automotive industry places primary emphasis on performance, styling, and comfort.

Automobile production volumes are huge. Ford Motor Company alone sold more than six million passenger vehicles in 2003. Modern assembly lines produce vehicles at rates up to one per minute. Competition is ruthless, with a savings of US $1 per vehicle being regarded as significant. In this environment, 100% testing is difficult. Furthermore, there is minimal pressure on manufacturers to monitor components after selling their vehicles to consumers. These considerations lead to a heavy emphasis on increasing productivity, cutting costs, and eliminating operations perceived as unnecessary.

Traditional NDT: The nature of traditional NDT presents roadblocks to its implementation in an automotive setting. NDT is customarily performed by specialized personnel who know how to handle the sensors, operate the instruments, and interpret their indications. These operators are highly trained and must undergo periodic skills certification. From plant management's perspective, training and certification are expensive, and inspection personnel do not add to the quantity of product reaching the end of the line. On the contrary, the detection of flaws or other "discrepancies" can be seen as impeding production. The detection of a discrepancy can inaugurate a containment action, in which all product since the last inspection must be quarantined, individually inspected, and repaired or scrapped. Because a manual nondestructive test may be performed on as few as one or two parts per shift, a substantial amount of quarantined product can be accumulated, representing a serious added strain on already overworked personnel. Under such high-stress conditions, inevitable false calls can lead to demands to eliminate the test. On a high-speed production line, inspector variability and fatigue are significant concerns, and manual inspection is difficult to integrate with systematic tracking of results when neither the inspector nor supervisor has time to collect data centrally and examine it for trends and correlations.

Given this environment, ongoing utilization of NDT is critically dependent on plant acceptance. If the plant does not see the test as filling a critical need, it will be eliminated. Furthermore, once a process is brought under control (in the sense of Statistical Process Control) and maintained there for a period of weeks, NDT may be judged superfluous and subsequently omitted. Nevertheless, NDT does sometimes become established on the plant floor. A key consideration is whether the test relates to performance, appearance, or cost. In addition, safety-critical aspects are singled out for special attention. The driving factor in the decision to use NDT often is cost reduction, even when other benefits ensue.

Perhaps the most widespread automotive NDT application is leak testing, which is applied extensively to engines, fuel systems, air-conditioning components, and wheels. These parts simply don't function reliably or at all if they leak, and in some cases, like fuel systems, leaky components may present a safety hazard. Air-pressure decay is the most frequently chosen test method, although helium sniffing finds some applications. These low-tech tests are simple and direct, but, because of the large number of parts, they are often automated. Take as an example cast parts. Castings often contain porosity and oxide inclusions, an excess of which allows fluids to permeate through. Fluids in affected engines can migrate to places where they do not belong. Tires mounted on affected wheels can deflate. It should not be surprising, therefore, that plants leak check finished engines and wheels. Yet leak checks are also performed at earlier production stages to avoid the high cost of further machining and assembly. Thus cost reduction drives the testing regimen.

Eliminating scrap and waste that result from destructive testing can generate worthwhile cost reductions. Case depth of hardened parts is measured using eddy current or ultrasonics to avoid "saw cut" sectioning followed by manual measurement of case depth. Likewise, the thicknesses of the various layers in plastic fuel tanks are measured ultrasonically in place of sectioning, staining, and measuring under a microscope [3]. The business case for these tests is based on reducing not only the financial impact of scrapping otherwise saleable parts but also the labor and other costs associated with the destructive approach.

Automotive NDT is often performed in suppliers' facilities. Suppliers have additional incentives beyond those operative in OEM (original equipment manufacturer) plants. An OEM can require that its supplier perform specific tests to document the quality of its products before the OEM will accept delivery. As a case in point, Ford specifies eddy-current inspection of all welded tubing for brake and fuel lines. In addition, deficiencies in certain supplier products become apparent during further production. A supplier is highly motivated to eliminate flaws in tailor-welded blanks, for instance, because such flaws become evident during subsequent stamping operations.

These are some examples of automotive NDT that have been integrated into production. It should be noted, however, that metrology staff have access to additional inspection procedures. Some, like hardness measurements to confirm correct heat treatment of castings, are used by lab personnel to routinely monitor the state of affairs in the plant. Others, like radiography and ultrasonics, are brought into service as diagnostic tools on an as-needed basis. The fact that certain inspections are not performed on a daily basis does not minimize their importance for maintaining quality.

Overcoming Roadblocks: Successful implementation of NDT in automotive plants entails viewing the situation from the viewpoint of plant management. Management cares only about "real" problems, ones they know they have and know they need to solve. Only solutions that take the realities of the plant environment into account, including cost considerations and production rate, have any hope of being implemented. Learning to see matters from plant management's perspective enhances an NDT advocate's likelihood of success.

A major reality in automotive plants is the need to minimize costs, including the cost of inspections. Because labor is the second largest variable cost in plants, after materials, reduction in dependence on trained inspection personnel is attractive. Ways to achieve this include using automation to enhance precision and reduce fatigue, and incorporating intelligence into inspection instruments to minimize human error.

Incorporating intelligence into instrumentation is illustrated by developments in nondestructive spot-weld inspection. In the method widely practiced in European plants [4], an operator places an ultrasonic probe on a weld, shifting its location and orientation until a suitable A-scan is obtained. The quality of the result depend on the operator's skill at performing these manipulations. In response, vendors have developed systems using colour patterns in place of detailed ultrasonic knowledge to teach the operator how to optimize these adjustments. After locating and orienting the probe, the operator chooses to accept or reject the weld by interpreting the A-scan in terms of echo amplitudes, timing, and decay rate. Commercial systems are now available to assist with this complex decision. The next stage of this development may involve phased arrays, which are being explored as a means of minimizing location and orientation difficulties along with reducing the degree of detailed operator knowledge required [5]. Given the large amount of information available from an array, a C-scan presentation format is used, in harmony with the old idea that a picture is worth a thousand words.

Hand in hand with cost reduction comes the need to minimize interference with the smooth flow of production. One approach is to develop quicker inspections. Because many current inspection procedures are slow, they often require removing the part from the production line. Some new or blossoming inspection techniques are quicker. Machine vision rapidly and reliably determines correct location and orientation of parts and can detect certain types of flaws. Non-contact ultrasound, including laser-based and air-coupled methods, eliminates the need to apply couplant and bring a transducer into intimate contact with a part [6]. Resonance testing reveals properties of an entire assembly in a single test [7]. Infrared thermography offers rapid inspection of large surfaces.

While quicker inspections and smarter instrumentation help, there is a more meaningful way to minimize interference with production schedules. Inspections can be used to reduce bad product, not just to find it. This approach requires abandonment of the plant's traditional desire for a clear-cut Go/No-Go indication. Though unambiguous indication of deficient product does have value, from a process-control perspective attribute data is never preferable to variable data. Thus the principal benefit of quantitative inspection is its usefulness as a trend indicator. Timely corrective action in response to measured deterioration can avert the production of unsatisfactory parts.

A recent development in paint-shop practice demonstrates this shift in paradigm by incorporating paint-thickness measurement into closed-loop feedback control of spray-booth parameters [8]. Thicknesses of the several layers are measured accurately using an intelligent ultrasonic instrument, robotically manipulated to examine 100 key vehicle locations in a consistent and timely manner. Quality is substantially improved by updating process parameters on an automated basis many times per hour instead of twice per day. Productivity is increased, and paint costs are reduced via tighter process control.

The ultimate integration of NDT into production is in-situ process control. This strategy short circuits the notion of standalone inspections altogether. Instead, the inspection (if one can call it that) is incorporated directly into the production machinery and is used to determine when the machine process is correctly performed. Signature analysis of basic mechanical quantities is used to supervise machining operations [9]. Ultrasonics embedded into welding electrodes monitors the progression of the spot-welding process. Such systems strive to ensure 100 percent satisfactory outcomes by controlling each individual machine operation in real time.

Although promising for some applications, in-situ inspection systems do not always take plant realities fully into account. Whether the in-situ approach is suitable varies with the relationship between process complexity and instrumentation cost. Low volume, high value-added processes that can be monitored using inexpensive sensors benefit from this approach. Monitoring of machining operations using force and vibration sensors falls in this category. High volume operations, on the other hand, are probably not suitable candidates, especially if the inspection technology is expensive. Consider spot welding. Because several welding machines are required to weld any particular subassembly, and because inspection capability would need to be added to every machine, the capital expense for in-situ ultrasound is likely to be inordinately high. Moreover, since any particular machine would make substandard welds only infrequently, the business case for the necessary investment may be weak.

For high volume operations, like spot welding, it probably makes more sense to use automated, on-line, post-process inspection. Here is a scenario. By using an automated test on line, as opposed to a manual test off line, dependence on trained personnel and interference with production flow is minimized. By inspecting a subassembly after all welding operations on it have been completed, as few as one NDT inspection instrument could suffice for the entire subassembly. Because insufficient time is available to inspect all of the multiple welds on each unit, the robot inspects different welds on successive units, assessing all welds on a regular, short cycle. In addition to flagging unsatisfactory welds, the system quantitatively tracks successive measurements at each weld location, thus ensuring timely feedback before the upstream process can degrade to the extent of producing substandard welds.

Opportunities: Even an inspection technology that is attractive by the preceding criteria faces yet one more hurdle: the inertia of the status quo. The plant may be comfortable with the way they do things now, even if it generates scrap and wastes human resources, for no better reason than having done it that way for many years. The plant may insist that NDT achieve an unrealistic or outmoded standard. There may be lack of floor space to install new instrumentation or lack of appropriate procedures for logging and tracking the results. Such barriers can stymie even the most dedicated and well intentioned person.

Therefore the ripest opportunities for expanding NDT in the automobile industry coincide with the introduction of new materials and processes. New materials are being introduced in the continuing quest for safer and more fuel-efficient vehicles, and new processes are considered to reduce costs and increase quality as well as to enable the use of the new materials. If these are coming anyway, the argument from tradition loses its relevance. Production lines do not yet exist; prejudices are not yet formed; procedures are not yet established. Furthermore, new materials and processes bring new problems and challenges to which NDT offers solutions.

New materials currently being introduced or under consideration include advanced high-strength steels, aluminum, magnesium, and composites. Each brings unique complexities. New joining processes include self-piercing rivets, laser welding, friction stir welding, and ultrasonic welding. Adhesive bonding presents issues of ensuring the right component mix, correct placement, and proper cure. Modern die castings contain flaws not seen before. Traditional paint systems face competition from wet-on-wet and powder processes and from film laminates. The impact of new products should also be contemplated. The production of hybrid vehicles enhances the automotive importance of energy-storage media, high-power electronics, and electromechanical machinery, and fuel-cell vehicles are an all new technology with all new problems. Each of these presents fresh challenges to the industry and, correspondingly, new opportunities for NDT.

Conclusion: Because of huge production rates and intense competition, NDT can be tricky to implement in the automotive sector. Barriers include the cost of inspection instrumentation and personnel, the pressure to maximize production flow, and the inertia of the status quo. Forward progress can be made through automation and the use of intelligent instrumentation, and by taking advantage of the trend-indicating nature of quantitative measurements to reduce or eliminate bad product. New NDT opportunities are opening up through the confluence of two trends: steady advancement in the state of the NDT art and the accelerating introduction of new automotive materials and processes.

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