Energy regeneration systems

Friction Stir Welding
new technology and repairability

AEB
not all systems are the same!
Energy regeneration, or energy recovery, regenerative braking, and KERS are all based on a similar concept of recovering wasted energy under deceleration and braking to be stored and used at another time.

This technology is most frequently found on Hybrids and Battery Electric Vehicles, but is increasingly found in other ranges to improve efficiency and reduce emissions.

Typically referred to as Regenerative Braking, this is probably a misnomer as recovery is not always during braking and not related to the braking system. But Energy Regeneration undoubtedly includes regenerative braking.

These systems are quite diverse in operating characteristics and componentry between different manufacturers and, in some cases, between different model ranges.
Lexus Hybrid Drive for RX450

The Lexus RX450h is a 4WD hybrid that employs two electric motors, one on each axle. The front is 123Kw and the rear is 50Kw. The vehicle can drive on electric power only for a limited distance at lower speeds using these motors and the motors support the 3.5litre V6 petrol engine during normal operation.

However, during deceleration or braking the Power Control Unit (PCU) shuts down the petrol engine and both electric motors become generators. This is in conjunction with the hydraulic braking system, with a different proportion of regenerative braking during different phases of the braking action. This is termed as Electronic Controlled Braking by Lexus. The energy generated is converted from AC to DC by the Inverter and is then stored in the High Voltage Battery pack.
Toyoda Prius HSD

As you’d expect from the parent company of Lexus, the Toyota system for the Prius is very similar. Though a front wheel drive only vehicle, the Prius also has 2 electric motors. The main 60kW motor works in parallel with the petrol engine, or can power the front wheels alone for electric drive. The other motor is a smaller 42kW unit that functions as a generator providing charge to the High Voltage battery pack and as a starter motor.

But during braking the main 60kW motor also acts as a generator, alongside the 42kW motor, providing charge through the inverter to the battery pack. Again, the amount of hydraulic and regenerative braking is proportionate as seen below.

As you can see, both these systems are internal to the driveline and therefore unlikely to suffer from impact damage, unless the engine & transmission has taken direct damage. The inverter that converts the DC to AC (and AC to DC) is the most exposed component, typically located at the front of the engine bay.
BMW Brake Energy Regeneration – Efficient Dynamics

BMW, as part of their Efficient Dynamics range of technologies which is incorporated throughout their range, feature Brake Energy Regeneration. This is quite different from the Toyota & Lexus systems as this is not restricted to BMW’s few hybrid models.

ActiveHybrid: With the ActiveHybrid models, the electric motor functions as a starter motor and boosts the engine during acceleration. This motor becomes a generator during deceleration and braking, similar to the Prius’ system. This 120V motor is installed directly on the crankshaft and is therefore directly and permanently connected to the engine. As much braking as possible is done through the electric motor to recapture energy for the high voltage battery. This 120v alternating current is converted to DC by an inverter.

Conversely, when accelerating, the alternator is disconnected so that all the power from the engine is directed towards driving the wheels, rather than energy generation at this inefficient time.

The system does also monitor the battery charge level and will activate the alternator during acceleration too if the battery level is too low.

This requires an AGM battery. AGM (Absorptive Glass Mat) uses glass fibre mat pouches of electrolyte between the plates. These are more tolerant of fast and frequent charging, so suitable for regenerative braking whereby the alternator is charging each time the vehicle decelerates or brakes.

Electric only drive is not possible with this system

Conventional: With the conventional BMW system the alternator is not permanently connected as with a conventional system. The alternator is activated by braking or decelerating, generating charge from the otherwise wasted energy which is then stored in the conventional battery.
Volvo hybrid

The Volvo system employed by the V60 hybrid is different again. This vehicle has a 2.4litre D6 turbo-diesel driving the front wheels. The ERAD (Electric Rear Axle Drive) features a 70hp electric motor driven by an 11.2kWh lithium-ion battery pack. In 4WD mode the ECU apportions power between the diesel driven front axle and the electrically driven rear.

The hybrid system is selectable by the driver who is able to choose diesel, electric, or both at the touch of a switch.

But, unlike the Toyota hybrids, the Volvo still includes an alternator. The V60 hybrid is a plug-in model that can be charged through a regular 230v socket, but should there be insufficient charge this alternator will engage to charge the battery pack for all-electric driving when required. The alternator will also ensure a sufficient level of charging for the rear axle motor in 4WD operation.

Mechanical and regenerative braking is proportionate again. Initial braking is by using the rear axle motor as a generator, (charging the battery pack), with mechanical braking used only when more braking effort is required.
With introduction on the 2013 Mazda 6, i-ELOOP (intelligent Energy Loop) is a new regenerative system that uses a capacitor to store electrical energy. Mazda’s philosophy is that this negates the use for either dedicated electric motors or battery.

The system comprises of a variable voltage alternator (12V to 25V), a DC/DC Converter and a Double Layer Capacitor (commonly known as a super-capacitor).

The system comes into operation as soon as the driver begins to decelerate, with the alternator generating electricity at up to 25V. This can be sent directly to the EDLC (Electric Double Layer Capacitor) which can quickly accept and store this charge. This is then passed through the DC/DC Converter which reduces this to 12V for use by the vehicle system. The system is purportedly more efficient for stop-start driving as the engine is not needed to generate electrical energy.

**Summary**

There is an inherent diversity in the types of energy regeneration available as could be expected after separate development by different vehicle manufacturers. But the basic functions are fairly similar with hybrids and EV’s using electric motors as generators and non-hybrids using alternators, though in different ways.

Most of the core components are present anyway so this technology is not adding much cost or complexity. The non-hybrid systems are not, as yet, using much in the way of higher voltage, but it should be remembered that a capacitor will hold a charge even after the battery is disconnected.

Components such as the Inverters and maybe also a capacitor (such as the Mazda EDLC) may be in the potential impact zone. But the EV’s and hybrids need Inverters anyway, and capacitors are features of many stop-start systems already.

What is clear is that these systems are increasingly common as manufacturers strive for greater and greater efficiency. The consistent operating characteristics of cars can no longer be taken for granted.
MUCH HAS BEEN MADE OF FRICTION STIR WELDING (FSW) in recent months, particularly in terms of it as a “new technology” and repairability. But it is not new and Thatcham researched this years ago, working in conjunction with vehicle manufacturers who were trialling this at that time.

SOME EXAMPLES ARE SEEN ON MAZDA VEHICLES, FOR JOINING OF ALUMINIUM SHEET ON THE MX5 AND ALSO BY TOYOTA ON THE PRIUS.
The process was developed and patented by TWI Ltd in 1991. A rotating cylindrical tool with a profiled nib is drawn along a butt joint between the two materials for joining. As the name implies, frictional heat is generated to soften the material WITHOUT melting. Constant pressure is applied and the profile forces the softened material toward the rear of the tool where they are forged together. The nib is not quite as deep as the weld depth required.

There are many factors to be considered by the manufacturer using this process, most notably the rotation speed and speed at which the tool is drawn across the surface. The quality of the join is directly related to the right combination of these two factors.
Further development of the process has been to trial dual-rotation FSW, whereby the tool outer shoulder rotation is contrary or proportionately not as fast as the nib rotation. This has the effect of reducing the temperature of the outer edge of the weld whilst maintaining the effectiveness of the process at the tip.

There is a related process known as Friction Stir Spot Welding (FSSW) which is the same process with a rotating tool being plunged into the material, but in this case there is no lateral drawing of the tool across the panel. As it is a spot it is used for stacked panels, and the tool is drawn deeper into actual contact with the material being joined once the plastic softened state has been reached. Friction Stir Spot Welding was used on the Mazda RX8 for the rear doors and for the bonnet structure.
Most commonly FSW has been used for aluminium, not just restricted to the automotive industry; having been used for ship building, nuclear fuel canisters and even for the SpaceX rockets. The process is being adapted for other materials including magnesium and copper. Going forward Apple has suggested they will be using FSW to create thinner and more elegant cases for their next generation iMac computers.

Honda is one manufacturer that has further developed the technology to join two different materials; most notably the joining of steel and aluminium to produce the front subframe for the 2013MY Accord.
WHY & WHERE IS IT USED?

The driving factor so far seems to be efficient production process. A recent example is the Mercedes SL (R231). As the car is a convertible and needed structural strength and rigidity, aluminium was chosen as the predominant material. There are 3 box profiled floor sections on each side of the transmission tunnel; incorporated for stiffness, but also because the profiles give good crash impact performance.

**MERCEDES USED FSW TO JOIN THE 6 PROFILES TO EACH OTHER AND THE SURROUNDING STRUCTURE AS THIS PROCESS INDUCES LESS HEAT DISTORTION WHICH LEADS TO GREATER BODY ALIGNMENT QUALITY.**

But also they selected FSW over laser welding since using FSW meant that the vehicle body would be at that particular weld station on the production line for far less time, as less heat and resultant cooling is required. This results in better overall production efficiency; production time is reduced by 26% over the predecessor R230 model.

Similarly, the process was chosen by Land Rover for subframe mounts for the new Range Rover (L405) as again it did not induce heat distortion for this critical mounting point.
Thatcham does not believe so. Very few of the locations where Friction Stir Welding has been applied present an issue for insurers in repair. As can be seen with the R231 Mercedes SL, the use is deep within the floor structure. So for the vast majority of repairs FSW areas will not be seen. (Mercedes have stated that they have taken many engineering decisions on the R231 with repairability in mind as the Mercedes SL is a prestigious car that tends to become an appreciating classic).

In the case of the Honda Accord, where FSW is limited to the front subframe, it is unlikely that any repair will involve reattaching the two halves of the subframe. And as some magazines are suggesting, the next generation Accord may not be brought to the UK market as sales on non-UK built Honda’s have been weak, with only 1500 being sold so far in 2012.

If Friction Stir Spot welding application is increased then this would create far more of a problem for repair and Thatcham will monitor manufacturer developments in this direction. But so far its application in areas such as door frames has not been an issue as these will not require re-joining in repair, but instead will be replaced by a complete door panel.

IS THERE ANY CAUSE TO WORRY?
At the moment there are 6 different technological configurations for Autonomous Emergency Braking systems across the vehicle manufacturers. These are:

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<thead>
<tr>
<th>System</th>
<th>Technology</th>
<th>Models</th>
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<tbody>
<tr>
<td>Ford Active City Stop</td>
<td>LIDAR</td>
<td>Ford Focus, Various Volvos, Mazda CX5 &amp; 6, Fiat Panda &amp; 500L, VW up!</td>
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<tr>
<td>Volvo City Safety</td>
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<td>Mazda</td>
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<td>Fiat</td>
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<td>VW</td>
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<td>Skoda</td>
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<tr>
<td>Seat</td>
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<tr>
<td>Honda Collision Mitigation Braking System</td>
<td>RADAR</td>
<td>Honda CRV, CRV/Legend/Accord/Civic, Mitsubishi Outlander, Toyota Prius</td>
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<tr>
<td>Forward Collision Mitigation</td>
<td></td>
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<tr>
<td>Toyota Pre-Crash Safety System</td>
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<tr>
<td>Audi Pre-Safe Braking</td>
<td>RADAR fusion</td>
<td>Various Mercedes, Audi Pre-Sense Plus</td>
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<tr>
<td>Audi Pre-Sense Plus</td>
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<tr>
<td>Subaru Eye Sight system</td>
<td>Stereo Camera</td>
<td>Not in UK</td>
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<tr>
<td>Volpe Collision Warning with Auto-Brake and Pedestrian Detection</td>
<td>Camera &amp; RADAR fusion</td>
<td>Volvo V60, V40</td>
</tr>
<tr>
<td>Mercedes</td>
<td>Stereo camera &amp; radar fusion</td>
<td>Mercedes S class &amp; E class from 2013MY</td>
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</table>

However, the functions of the core components are generally consistent and it is important to remember that these systems do not function alone, but in combination with other Advanced Driver Assistance and stability systems. There may be some fairly complex calibration processes for these AEB and FCW (Forward Collision Warning) systems, but these may not be required for every repair/replace operation as some will be immediately operational and some may self-align.
Honda

The 77GHz millimetre wave radar for the Honda CMBS, which has a 100 metre range and a 16 degree field of view, is located immediately behind the grille emblem.

This is by necessity a fairly exposed location, both to potential accident damage and to road debris, though the emblem or badge does mitigate this somewhat. Honda recommends keeping the grille emblem clean to avoid compromising the radar performance.

(Note: some manufacturers are already mounting the radar unit in locations such as a cut-out in the front bumper reinforcement where it is far better protected).

For replacement, the fitment angle of the radar into the mounting bracket is critical and there is a fairly complex calibration procedure to ensure accuracy of CMBS Systems.

Honda CMBS operates at vehicle speeds of above 9mph, or if relative speed between the vehicle and the vehicle ahead is above 9mph. Upon closing on a vehicle ahead the system will issue a visual and audible warning, what Honda calls the 1st stage warning. Should the distance to the other vehicle continue to decrease to the point where there is a high collision risk, the system give a 2nd stage warning by retracting the seatbelts gently and finally automatic pre-impact braking when the collision is deemed as being unavoidable. If the driver fails to react and a collision is imminent then the system will activate emergency braking.

The CMBS system is controlled by the Adaptive Cruise Control (ACC) control unit under the facia. This integrates with the various driving systems, as required, via the CAN bus. For example, the ESC (known as Vehicle Stability Assist for Hondas) will also operate during emergency braking. The Radar sensor communicates with the ACC control unit, which is also continually monitoring brake fluid pressure sensors. As differing levels of risk develop the ACC control unit instructs the VSA Control Unit to pre-pressure the braking system, before initiating the emergency braking.

The screen unit clips and unclips to enable windscreen repair or removal/refix.

Obviously, when in conjunction with the ACC, the brake pressure would be released and the vehicle would resume its pre-set speed once the other vehicle is out of the way.
The Volvo City Safety system uses LIDAR behind the front windscreen. This is the location of what Volvo has named the Closing Velocity Module (CVM). It is located with the rain sensor for the windscreen wipers. This is a more complex system, but although the radar is still relatively exposed at the front of the vehicle behind the grille, these other components are located higher up and away from most harm behind the windscreen.

There may also be radar behind the front grille for optional Forward Collision Warning.

The City Safety system is automatically in a “ready” state each time the engine is started as a default.

The driver can switch it off, but it will turn on again each time the car is re-started. The CVM utilises a LIDAR (Light Detection and Ranging) laser transmitter, of 905nm wavelength and 45mW power, to survey immediately ahead of the vehicle. The CVM then measures the reflected laser light to assess the distance and speed differential to the vehicle ahead and the CVM is continuously communicating with other vehicle systems, again via the CAN bus.

The CVM area is in the swept area of the windscreen wipers and should be kept as clean as possible. The system also gives a warning to the driver if the LiDAR sensor is obscured by frost or other contamination, or if the driver has deactivated the system.

Note: This is a laser, so care must be taken not to look directly into the transmitter

The CVM can instruct the Brake Control Module to pre-pressure the braking system, initiate emergency braking and activate Emergency Brake Assist to provide optimal braking force when required. It can also limit engine torque. As the BCM is an integral part it is important that the steering angle sensor is reset to zero after any wheel alignment operations.

To prepare for an imminent collision the CVM communicates with the SRS control module to pre-tension the seatbelts.
**Subaru**

Subaru have a system called EyeSight, (not yet available in the UK) using a pair of cameras to give a stereo vision system which integrates with 7 driver assist systems including Pre-Collision Braking System, Pre-Collision Brake Assist, ACC, Lane Departure Warning and Pre-Collision Throttle Management.

**Toyota**

Toyota uses a single 77GHz radar based system like the Honda CMBS; the Toyota System known as Pre-Crash Safety system. This again has a front grille mounted radar system. This system gives an audible warning to the driver of collision risk. It will also activate brake assist to prepare for braking and then, if collision is imminent, activate the brakes to reduce impact speed when the collision is deemed unavoidable. The SRS will prepare the seatbelts for restraining the occupants.

As with these other systems, correct calibration is required if the RADAR is replaced.

**Delphi**

Delphi is a developer and supplier of Collision Mitigation System (CMS) to vehicle manufacturers. Their CMS is a combined radar and forward-camera system that offers a number of features as part of an Adaptive Cruise Control package with FCM and AEB functions.

The radar is designed to be mounted on the front panel behind the grille or front bumper, with a dual mode that can simultaneously project 60 metres with a 90 degree field and 175 metres with a narrower 20 degree field.

Delphi offers a range of Forward Cameras for their customers with varying fields of view and image processors. They have an integrated RADAR and camera package that is small enough to be mounted on the back of an interior mirror.
**What you can’t see**

These components are sophisticated but there is far more to AEB than adding a camera and RADAR to the ESC and braking systems. What you cannot see is the complex software and algorithms that enable the car to make the right decisions. The AEB system needs to assess the road ahead and make a logical assessment of the collision risk. It also needs to be able to identify multiple objects, calculate their distance, direction and relative speed. For LIDAR systems the laser reflection, from the transmitter to 3 receivers, need to be sorted and an image rapidly produced. This is further complicated by the laser reflecting from different materials at different ranges in different ways. The sensors may therefore use multiple channels consecutively to build up an effective 3D image quickly.

Camera systems use complex software to recognize lane markings (for Lane Keep Assist functions), recognise light spots, distance and velocity. Despite being relatively low resolution, the frequency of frame rate and the response speed enables good analysis of hazards on the road ahead. The software for the image can identify surroundings and build and compare pictures to function as a motion detector. This enables tracking of multiple approaching objects.

Lasers are typically better at distance/range measuring, whereas cameras have the advantage of being less affected by weather. The systems and software need to be able to “talk” with the vehicle systems, possibly across a range of models. This is of particular importance to developers who supply these systems to vehicle manufacturers as customers.

**Future developments**

Demand for these systems will drive further developments. Star Rating could be substantially affected as Euro NCAP requirements include AEB fitment and effectiveness. In the UK, Insurance Group Rating will reward for standard fitment and performance, which may result in a reduction of 2 or more groups.