Emerging technologies and market trends in automotive transmissions

By Michael Murphy
Table of Contents

Chapter 1: Executive Summary ..................................................... 6
Global patterns of growth and development in automotive transmissions ........................................ 6

Chapter 2: Transmission technology development drivers and challenges ............................................. 9
Fuel economy ............................................................................ 9
Launch and shift quality ............................................................... 14
Packaging, weight, torque density and ratio spread ......................... 18
Noise, vibration and harshness (NVH) ........................................ 21
Lubrication .............................................................................. 23
Bearings ................................................................................... 28
Cost .......................................................................................... 30
Simulation ................................................................................ 31
Sensors ..................................................................................... 36
Testing ....................................................................................... 37

Chapter 3: Manual transmissions .................................................. 39
The effects of engine down-sizing and down-speeding ....................... 39
The dual-mass flywheel ................................................................. 40
Advances in synchroniser friction materials .................................... 43
Electronic clutch assistance ......................................................... 45
Two-shaft manuals .................................................................... 47
Three-shaft manuals .................................................................. 48
The global manual transmissions market ....................................... 48

Chapter 4: Automatic transmissions ............................................. 50
Planetary gear set designs ............................................................. 51
Advances with launch devices ....................................................... 52
Torque converters ...................................................................... 52
Torque pulse dampers ................................................................ 53
The ZF Hydrodynamically cooled clutch ....................................... 54
Internal clutches and brakes ........................................................ 55
Wet-clutch return springs ............................................................. 55
The Selectable One-way Clutch .................................................... 56
Stop-start functionality ................................................................. 57
Torque sensors .......................................................................... 60
Manual override systems on automatic transmissions ....................... 62
The challenges of research and development .................................. 62
Four- and five-speed automatics ................................................... 64
Six-speed automatics .................................................................. 64
Seven-speed automatics ............................................................... 68
Eight-speed automatics ............................................................... 69
Nine-speed automatics ............................................................... 71
Ten-speed automatics ................................................................. 72
The global planetary automatic transmissions market ....................... 72

Chapter 5: Single-clutch automated manual transmissions ............. 74
Addressing the shift-quality challenge .......................................... 75
The global single-clutch AMT market ............................................ 77

Chapter 6: Dual-clutch transmissions ............................................ 78
Clutch technologies .................................................................... 78
Clutch friction materials ............................................................... 80
Actuator technologies ................................................................. 81
Control units ........................................................................................................... 84
Double-clutch bearings ........................................................................................... 86
Production DCTs ...................................................................................................... 87
Innovative DCT concepts ......................................................................................... 88
The global DCT market .......................................................................................... 90

Chapter 7: Continuously-variable transmissions ....................................................... 91
Variator pulleys ......................................................................................................... 93
Belts .............................................................................................................................. 93
Chains ........................................................................................................................ 94
Actuators and pumps .................................................................................................. 94
Production CVTs ....................................................................................................... 95
Infinitely-variable transmissions ............................................................................... 97
The global CVT market ............................................................................................ 101

Chapter 8: Hybrid-electric vehicle transmissions ..................................................... 102
Planetary hybrid transmissions ................................................................................ 102
Planetary automatic hybrid transmissions ................................................................ 104
AMT hybrid transmissions ...................................................................................... 105
DCT hybrid transmissions ....................................................................................... 106
CVT hybrid transmissions ....................................................................................... 106
The General Motors Volttec transmission ............................................................... 109
Novel hybrid-electric transmission concepts ........................................................... 110
The global hybrid-electric vehicle transmission market ............................................. 115

Chapter 9: Electric vehicle transmissions ................................................................ 116
Single-speed EV transmissions ................................................................................ 118
Two-speed EV transmissions ................................................................................... 119
Three-speed EV transmissions ............................................................................... 122
Multi-speed EV transmissions ............................................................................... 124
The global hybrid-electric and electric vehicle transmissions market ....................... 125

Chapter 10: Transmission market forecasts ............................................................. 126
Global ....................................................................................................................... 126
Europe ...................................................................................................................... 129
North America ........................................................................................................ 130
Japan and South Korea ............................................................................................ 133
Greater China .......................................................................................................... 135
South America ......................................................................................................... 137

Profiles
Aisin Seiki ................................................................................................................ 138
BorgWarner ............................................................................................................ 143
Chongqing Tsingshan .............................................................................................. 148
Delphi ....................................................................................................................... 151
Eaton ......................................................................................................................... 154
Getrag ......................................................................................................................... 158
INA ............................................................................................................................. 162
JATCO (Japanese Automatic Transmission Company) ............................................ 165
Magneti Marelli ...................................................................................................... 169
Oerlikon Graziano ................................................................................................... 173
Shaanxi Fast Auto Drive Group Company ............................................................ 176
Valeo ......................................................................................................................... 179
ZF Friedrichshafen AG ......................................................................................... 183
Zhejiang Wanliyang Transmission ........................................................................ 186
Table of figures

Figure 1: Eight drivers of transmissions development ........................................... 7
Figure 2: CO2 emissions targets in major markets converted to NEDC .......................... 9
Figure 3: Automatic transmission fuel economy gains since five-speed units .................. 11
Figure 4: Technology advances and improved efficiency of wet-clutch, six-speed DCTs ........ 12
Figure 5: Efficiency of automatics (AT), DCTs and CVTs, present and past .................... 12
Figure 6: Comparison of the efficiencies of different transmission types ....................... 13
Figure 7: Traction diagrams for a NA ICE with six- and nine-speed transmissions .......... 13
Figure 8: Launch response comparison of automatic (AT) and DCT with turbocharging ...... 15
Figure 9: AVL shift line driveability (DRB) optimiser ................................................. 17
Figure 10: Jatco Adaptive Shift Control ..................................................................... 17
Figure 11: Global vehicle segment trends .................................................................. 18
Figure 12: Global engine cylinder count trends ........................................................ 19
Figure 13: Ratio spread of AT, DCT and CVT, present and past ................................. 20
Figure 14: Full load engine torsional fluctuations ....................................................... 20
Figure 15: Gear tooth force level versus torque at pinion: stage 1 & 2 ......................... 21
Figure 16: Noise level comparison: standard push belt vs two belts with improved element sequence .............................................................. 22
Figure 17: Synchroniser cut-off sleeve ...................................................................... 23
Figure 18: Acrylic transmission housing used for oil flow analysis ............................. 24
Figure 19: One piece gear wheel and two-piece steel equivalent ................................. 24
Figure 20: Principles of component shielding ........................................................... 23
Figure 21: Principles of a high-level sump ................................................................. 25
Figure 22: Stribeck curve of coefficient of friction versus (viscosity x velocity)/load ........ 26
Figure 23: Different additive mixes typically in gear oil and ATF ................................. 26
Figure 24: Coefficient of friction over time, wet clutches in oil A, oil B and oil C .......... 27
Figure 25: Comparison of Shell GTL ATF with Group III synthetic ATF C ................. 27
Figure 26: Friction reduction using optimised bearings on an AT main shaft ............... 28
Figure 27: Bearing friction torque at 50kph: deep-groove ball bearings (dgbb) versus tapered roller bearings (trbs) .............................................................. 29
Figure 28: Bearing friction torque at 50kph: deep-groove ball bearings (dgbb) versus tapered roller bearings (trbs) .............................................................. 30
Figure 29: Efficiency of automatics (AT), DCTs and CVTs, present and past ............... 30
Figure 30: Importance of transmission attributes by region ....................................... 31
Figure 31: Simulation and actual measurement of secondary flywheel side speed during diesel engine start ................................................................. 32
Figure 32: Modelling of transmission durability with ICE changed from gasoline to diesel ................................................................. 32
Figure 33: Simulation projects during the development of the GM M1x transmission .......... 33
Figure 34: Flow field comparison of the PIV data with the second CFD solver results ....... 34
Figure 35: Optimisation of axial oil flow within a wet clutch using simulation ............... 35
Figure 36: Axial flow distribution optimised using CFD ............................................. 35
Figure 37: Sensor technology guide ......................................................................... 36
Figure 38: Schaeffler dual-mass flywheel with centrifugal pendulum-type absorber ....... 40
Figure 39: Performance of a DMF versus a traditional clutch spring damper .............. 40
Figure 40: The principle of rolling cylinder deactivation on a three-cylinder engine ......... 41
Figure 41: Order analysis of RCD 1.5 operation with a centrifugal pendulum-type absorber ................................................................. 42
Figure 42: HOERBIGER hybrid synchroniser ring ...................................................... 42
Figure 43: Friction performance comparison: woven carbon synchronisers with two different lubricants ................................................................. 44
Figure 44: LuK e-clutch designs ............................................................................. 44
Figure 45: LuK hydrostatic clutch actuator (HCA) ....................................................... 45
Figure 46: Relative cost of manual, e-clutch, AMT and DCT ........................................ 46
Figure 47: Single-lay-shaft ZF six-speed manual transmission .................................... 46
Figure 48: Two-lay-shaft manual transmission schematic .......................................... 47
Figure 49: Manual transmission proportion in new cars in the US, 1975 - 2011 ............. 48
Figure 50: Market share of manual transmissions <250Nm in Europe ......................... 49
Figure 51: Simple epicyclic planetary gear set ............................................................ 50
Figure 52: Ravigneaux gear set ............................................................................... 51
Figure 53: Vibration as a function of damper spring stiffness ratio .............................. 52
Figure 54: LuK spring mass and pendulum damper .................................................... 53
Figure 110: Engine speed over time: T-Box IVT versus J5 five-speed manual
Figure 108: Schematic of the Ultimate Transmissions TBox IVT
Figure 107: Ratio spread comparison: CVP versus Lepelletier design six-speed
Figure 106: VariGlide transmission cross-section
Figure 105: Schematic of the CVP
Figure 104: Comparison of torque delivery during conventional and supported upshift
Figure 103: Jatco CVT7
Figure 102: The effects of over-clamping on efficiency of a CVT
Figure 101: Sources of efficiency losses in a belt-driven CVT
Figure 97: Audi Multitronic link-plate chain and variator
Figure 96: Dry- and wet-clutch DCT production forecast to 2018
Figure 95: Schematic of FINEMECH ten-speed DCT concept
Figure 93: Comparison of conventional and supported shift
Figure 92: Getrag six-speed DSG250
Figure 91: Torque boost DCT ratio shift
Figure 90: Torque interruption during DCT ratio shift
Figure 89: Clutch fill time with the new-generation Tremec solenoid valve
Figure 88: Level of end-of-line rejects before and after the introduction of an automated design process for robustness
Figure 87: Energy requirements of valve hydraulic versus pump actuation
Figure 86: Drag loss advances in wet clutch friction materials
Figure 85: Hill start simulation with dry-clutch friction materials
Figure 84: Controlled cooling simulation during full-throttle launch
Figure 82: Component inventory in 7-speed manual, DQ200 DSG and MCA
Figure 81: Zeroshift synchronisers/drive rings
Figure 80: Easytronic clutch actuator
Figure 79: Global automatic transmissions market forecast (millions), 2014 to 2021
Figure 78: ZF 9HP
Figure 77: Second-generation ZF 8HP automatic transmission
Figure 76: Mercedes-Benz 7G-Tronic Plus automatic transmission
Figure 75: Average fuel economy improvements by transmission component on the 7G-Tronic Plus
Figure 74: Antonov TX6 automated transmission
Figure 73: Linearity and responsiveness of the SKYACTIV-Drive with a five-speed automatic
Figure 72: Mazda SKYACTIV-Drive transmission
Figure 71: General Motors GF6 transmission
Figure 70: Controlled torque converter clutch slip during acceleration tip-in
Figure 69: Bosch TEHCM seen from underneath a GM 6L80 automatic transmission
Figure 68: Clutch slip control hysteresis response
Figure 67: Electronically controlled clutch slip step response
Figure 66: Tiptronic shifter on a 2003 Porsche 911
Figure 65: Comparison of baseline transmission and one with the magneto-elastic sensor control strategy
Figure 64: Performance of a magneto-elastic torque sensor
Figure 63: NEC start performance versus baseline transmission with electric hydraulic pump
Figure 62: Schematic of normally-engaged clutch
Figure 61: BorgWarner accumulator control solenoid
Figure 60: Drag torque reduction, friction packs versus selectable clutches
Figure 59: Schematic of ratchet design in selectable clutch
Figure 58: Component numbers in selectable versus friction-plate one-way clutches
Figure 57: Torque drag with differing spring load tolerances
Figure 56: ZF Sachs’ Hydrodynamically cooled clutch
Figure 55: Torsional damping of conventional and pendulum dampers on a six-cylinder diesel engine

Table of Contents
Emerging technologies and market trends in automotive transmissions

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During 2013 bearing manufacturer NSK announced the development of a long-life tapered roller bearing for automotive transmissions that exhibits friction losses 40% lower than those of previous products. The rolling elements and the inner and outer races of the bearing were strengthened through special heat treatment processes.

At the same time the company announced the development of an extremely high-speed needle roller bearing for use in planetary gear set pinions that can help to improve the efficiency of automatic and hybrid transmissions by enabling rotational speeds up to 1.5 times higher than that of current high-speed needle roller bearings. Central to the bearing’s improved performance is a new coating on the bearing cage that reduces frictional drag and the consequent heat.

This also enables a width reduction of around 7% compared to a conventional high-speed equivalent, contributing to a reduction in transmission size and weight. In October 2014 NSK announced a long-life shaft that enables further reductions in the size and weight of planetary gear sets.

In December 2014 Thomas Wolf Senior Engineer for Powertrain and Steering at SKF presented research findings from the use of tailor-made, deep-groove ball bearings in place of the tapered roller bearings installed throughout an existing production three-shaft, six-speed, transverse manual transmission. The tapered roller bearings on the differential shaft were retained because the power loss improvement would be minimal because of its relatively low rotational speed and the risk to bearing robustness was considered to be too high (Figure 27).

While capable of supporting the axial loads normally carried by tapered roller bearings, deep-groove ball bearings exhibit less rolling resistance and better NVH characteristics. Tests at the 50kph (31mph) points on the NEDC cycle in third gear and at the 100kph (62mph) point in sixth gear indicated resistance reductions from 269W to 90W and from 577W to 195W, respectively (Figure 28).

Wolf asserted that reductions of that order translate to significant CO2 emissions savings of 3.07g/km for a gasoline vehicle and 2.29g/km for a diesel. He also pointed out that SKF is working to reduce the losses associated with the seals on the deep-groove ball bearings, which could result in further power loss reduction.
Although the steel cones against which the synchroniser rings acted tended to become more polished during the repeated test procedures, the main effect associated with the loss of friction appeared to be the breakdown of additives in the low-reference lubricant at the high temperatures reached under the high-load condition. Microscopy revealed that the woven carbon fibre became clogged with broken down lubricant material, which caused the loss of friction and failure of the synchroniser. The recovery steps observed seemed to be caused by the clogged material on the surface of the carbon fibre material being swept away along with some of the fibre so that the CoF increased suddenly before beginning to become clogged again.

**Electronic clutch assistance**

The growing demand for stop-start and sailing functions to reduce fuel consumption, along with the increasing interest in automated transmissions in developing regions, is stimulating the development of automated clutch operation on manual transmissions that provide fuel economy and driver convenience advantages but avoid the expense of the gearshift actuators and control systems necessary for full AMT functioning.

**Figure 45: LuK hydrostatic clutch actuator (HCA)**

![Image of LuK hydrostatic clutch actuator (HCA)]

Source: LuK

LuK has applied an innovative hydrostatic clutch actuator (HCA) design that was originally conceived for DCT application to three e-clutch solution concepts that provide different degrees of automated clutch operation: clutch-by-wire (CbW), MTplus and electronic clutch management (ECM). CbW and MTplus retain the clutch pedal while ECM provides two-pedal operation but retains the need for the driver to carry out gearshifts. The component requirements and functionalities of each concept are listed in Figure 44.

The HCA consists of a compact brushless electric motor with integrated power electronics that drives a spindle fitted with planetary gears to provide a high gear reduction. The spindle nut transfers its axial movement to the concentric piston of a master cylinder. A travel sensor measures the piston position and a pressure sensor prevents overload. The HCA is equipped with its own brake fluid reservoir.
However, slip control hysteresis, which is a measure of how quickly the amount of slip responds to regularly modulated clutch pressure, was found to be slightly worse than in a two-path system. The target range for slip was for a minimum of 10rpm and a maximum of 150rpm. As can be seen in the Figure 68, slip exceeded the 150rpm maximum at the points marked with a red asterisk.

Attenuation of torsional vibration performance with the three-path system was similar to that of the baseline two-path system. In conclusion, it was decided that there was no significant advantage provided by the three-path technology and its further development was not pursued.

Four- and five-speed automatics

At the beginning of the new millennium, four-speed units accounted for around 42% of new automatic transmissions with five-speed units accounting for almost all the rest. By 2012, despite six-speed units accounting for around half of the market and five-speed units being in rapid decline, four-speed automatics still accounted for around 23% because of the demand in low-cost markets. As recently as 2010, Jatco launched a new four-speed for transverse applications that shared around half of its components with its predecessor, of which the company had manufactured around 11 million during the previous decade. Jatco was able to make the transmission 12% shorter and 22% lighter by reducing its torque capacity 16.7%, using a narrower torque converter and eliminating one clutch. Overall, it required 16% fewer components, reducing production cost while fuel economy was improved, largely through earlier lock-up of the torque converter.

Six-speed automatics

As has been mentioned, the development of the Lepelletier gear set amounted to something of a breakthrough when ZF launched the technology in 2001 on BMW’s ‘myTronic’ transmissions. The Lepelletier design enabled a 30% reduction in component numbers in a longitudinal automatic compared to the then current five-speed units while the count was even lower in transverse applications because a secondary shaft was no longer required.

Tests conducted by ZF indicated a 2% to 5% improvement in vehicle acceleration to 100kph (62mph) because of lower weight and closer ratios, and a 5% to 7% improvement in fuel economy because of those same factors together with the taller sixth gear that could be employed. Companies that took out licenses to produce Lepelletier gear sets included Aisin, Ford, General Motors, Jatco and Volkswagen.

The ZF transmission also incorporated Bosch’s first mechatronic control module with integrated electronic and mechanical components (Figure 69). This was advanced in 2005 with the launch of the company’s Transmission Electro Hydraulic Control Module (TEHCM) that incorporated sensors, solenoid valves and pressure controllers but eliminated the need for external connectors and cables. As a result, it could be installed within the transmission.

Late in 2014 General Motors launched the third generation of its global GF6 automatic transmission family for mid-size, transverse, front-wheel drive applications. The company claims a 4% fuel efficiency gain for the third generation compared to the second generation that was launched in 2011. The second-generation GF6 was claimed to provide a 2% fuel efficiency improvement over the first-generation model.

The gains achieved on the third-generation GF6 have been achieved through improvements that include a new off-axis, binary-mode oil pump, variable oil flow and a reduced oil level. An external accumulator has been added to enable stop-start functioning that can improve fuel efficiency by a further 3% to 5%. Since the first-generation GF6 was launched in 2008 it has been supplied to more than 100 small to midsize vehicle applications globally. All variants are based on the same architecture, share identical electrohydraulic control units and are manufactured on the same production lines.
DCTs were used on various motor sport applications during the 1980s but the first DCT to the mass market was the six-speed DSG250 developed by Getrag in collaboration with Volkswagen and launched in 2003 on Volkswagen and Audi products. BorgWarner claimed that the DSG250 (Figure 92) could execute gearshifts in eight milliseconds although Volkswagen was more conservative in claiming forty milliseconds. However, if the next gear to be selected was not the one already engaged, the shift could take up to 400 milliseconds. The DSG250 weighed 75kg, 50% heavier than a comparable manual.

Following the development of the DSG250, Getrag developed a family of six- and seven-speed DCTs using BorgWarner clutch modules that ranged as high in terms of torque capacity as 750Nm (542lb.ft). As well as supplying transmissions to OEMs, BorgWarner licenced the technology to others including BMW, Chrysler and Ford. The current front-wheel drive range includes the 6DCT250, the 6DCT450 and 6DCT470, all of which are six-speed units with torque ratings indicated in Newton-metres in the model number. In 2012, the company announced a new range of front-wheel drive DCTs based on the seven-speed 7DCT300 with a modular approach that enables the sharing of several components. They are equipped with electrohydraulic actuators and wet clutches, and feature optional water cooling of the housing. They include the six-speed 6DCT150 rated at 170Nm (123lb.ft) and the seven-speed 7DCT500.

The Australian company, Drivetrain Systems International (DSI), developed a seven-speed DCT. DSI was then sold to Geely. ZF developed a family of seven-speed DCTs for Porsche with torque capacities ranging from 500Nm (362lb.ft) to 780Nm (564lb.ft). Among other high-torque applications, Oerlikon Graziano developed a seven-speed DCT for the McLaren MP4-12C and Ricardo developed a seven-speed for the Bugatti Veyron.

Although Europe has considerable installed capacity for manual transmission production, first-generation DCT designs did not capitalise on this as much as was done with second-generation models. ZF has worked to achieve as much commonality of components as possible across its DCT families as well as with its manuals and Getrag is able to assemble multiple versions of its DCT families on a single production line. Meanwhile, Fiat Powertrain Technologies claims to have established the capacity to manufacture DCTs and manuals on the same production line.

DCT production is growing rapidly in China with, for example, Volkswagen Group and its Chinese joint ventures, FAW Volkswagen and Shanghai Volkswagen, producing the group's DSG. However, indigenous manufacturers have also developed the technology.
Equipping a planetary automatic transmission with stop-start function poses several challenges, which arise because of the way an ICE ‘flares’ during start-up with engine speed rising briefly. If the transmission is locked by engaging the friction clutches/brakes on two gears higher than first gear, the one-way clutch in the torque converter will provide hill-hold when the vehicle is facing uphill but not when it is on the flat or facing downhill because the clutch will operate in over-run mode. Researchers from Ford investigated several approaches to solving the issues of transmission torque mitigation by:

- Slipping the forward clutch during engine start,
- Locking the transmission with three clutches,
- Restarting the engine in a gear higher than first gear and shifting the transmission down immediately,
- Combinations of the above.

Varying the pressure on the forward clutch in 10psi indicated that transmission shock was least at 40psi, the highest pressure used, although turbine speed increased in the most stable manner at 20psi whereas it oscillated at the higher pressure. On average, the torque mitigation efforts achieved a 40% improvement and when combined with mitigation of the engine speed flare, launch performance, while found to be of slightly less quality by a customer clinic, were reported as “excellent” by the researchers.

In October 2014 Hyundai announced a new six-speed automatic transmission for HEVs that integrates the electric motor and almost all of the hybrid components within the transmission. The transmission employs a multi-plate clutch and a light torsion damper in place of the previous version’s torque converter and features an electric oil pump instead of the earlier mechanical one. At 130kg (287lb) it is lighter than the previous model but it is rated the same at 280Nm (202lb.ft) torque capacity.

**AMT hybrid transmissions**

AMTs have also been used in hybrid drivetrains. On FEV’s seven-speed 7H-AMT (Figure 116), which the company developed for the smaller vehicle segment, the electric motor helps to eliminate the torque interruption problem so commonly evident in AMTs. The 7H-AMT is capable of providing stop-start, limited electric-only power and acceleration assist. It has torque capacity from the ICE up to 320Nm (231lb.ft) and its electric motor can deliver 36kW (49hp) and 70Nm (51lb.ft) continuously.
Figure 145 shows a much lower market penetration of manual transmissions in North America with the technology almost disappearing by 2018. It also shows planetary automatics continuing to dominate more than is represented in Figure 155 because of lower market penetrations by CVTs. Figure 147 shows stop-start market penetration in North America increasing from only around 4.5% in 2015 to more than 55% in 2021 with volume increasing from less than one million to nearly ten million during the period.

Japan and South Korea

In Japan and South Korea, total transmission installation is forecast to decline 8% from around 14.7 million in 2012 to 13.5% in 2017. The planetary automatic segment with seven or more ratios is expected to increase 260% but from a small baseline in 2012, this will amount to only around 1.2 million units in 2017. Manuals with six ratios or more will increase 23% to around two million units while those with less than six ratios will decline 20% to around 1.35 million. DCTs and AMTs will also record strong growth, but 2017 volumes will still be small at around 600,000 units and 100,000 units respectively. Automatics with six ratios or less will decline by 28%.
INA is a subsidiary and one of the leading brands of Schaeffler which manufactures engine and transmission components for passenger cars.

Headquartered in Herzogenaurach, Germany, INA was founded in 1946 and has over 31,000 employees worldwide.

MANAGEMENT TEAM

- Klaus Rosenfeld is the Chief Executive Officer and Chief Financial Officer.
- Peter Gutzmer is the Chief Technology Officer responsible for monitoring new technology, ensuring upgrading products to latest technologies, and contributing in strategic decision making when it comes to adding new products to the portfolio.
- Norbert Indlekofer is the Chief Executive Officer responsible for the Automotive Division.
- Oliver Jung is the Chief Operating Officer responsible for overall operations.

BRIEF HISTORY

INA was founded by Dr. Wilhelm Schaeffler and Dr. Georg Schaeffler in 1946, and had its headquarters in Herzogenaurach, Germany. After three years, INA developed a needle roller bearing for industrial applications. In 1952 plain bearings were replaced by low-wear INA needle roller bearings in the transmission of a Volkswagen Beetle. A couple of years later in 1955, INA founded the new linear technology business unit. In 1956, rolling bearing production for the European market started in Haguenau, France. In 1965, Luk Lamellen, clutch manufacturer and Kupplungsbau GmbH were founded in Buhl, Germany and INA was one of the investors in these companies. INA enhanced its capabilities and built up a hydraulic valve lash to supply in Europe in 1971.

In 1984, the company made an investment in Helmut ELGES GmbH in Steinhagen to manufacture maintenance-free spherical plain bearings and rod ends. In 1985, Luk developed a dual mass flywheel, which set a new standard in the insulation of drivetrain noise. INA upgraded its hydraulic variable cam timers to allow continuous variation of valve timings in 1990 and FAG acquired the Barden Corporation to secure a strong position in the North American market. FAG developed automatic belt tensioner systems for passenger cars in 1986. In 1992, INA entered into the Korean market by establishing a plant in Ansan. Later in 1995, INA Bearings China Co. Ltd., was founded in Taicang. INA developed advanced equipments for testing wheelset bearing applications for rail vehicles in 1998. Luk introduced Continuously Variable Transmission (CVT) and hydraulic systems in 1999 and in the same year INA acquired all the shares of Luk and expanded its expertise as a system supplier to the automotive industry.

Luk’s automated manual transmission went into volume production as Easytronic in the Opel Corsa in 2000. In 2001, INA acquired FAG. INA, FAG, and Luk formed Schaeffler Group in 2003 and opened its automotive research centre in Troy, USA. In the same year INA developed a new manufacturing method for synchronizer sleeves used in Ford transmission. Subsequently, in 2004, direct drive technology was supplied by INA’s subsidiary company IDAM (INA Drives & Mechatronics). In 2005, the new plant in Brasov started producing linear products and components for industrial and automotive applications. Later in 2006, the company introduced its first multi-disc clutch with a self adjustment facility. Since then, the company has been continuously focusing on developing transmission technologies in order to reduce fuel consumption and emission in passenger cars.

CUSTOMERS

Audi, Fiat, Ford, Jaguar LandRover, Tata Motors, and Volvo are some of the major customers of INA.

May 2013  Technological agreement  With Aston Martin.  Integrated its 7-speed automated manual transaxle gearbox in the Aston Martin V12 Vintage S.

April 2013  Technological agreement  With Mercedes-Benz.  Incorporated 4WD hybrid parallel transmission systems in the Mercedes-Benz GLA 45 AMG.

March 2011  Technological agreement  With Lamborghini.  Integrated its 7-speed AMT in the Aventador model.

September 2008  Investment  Reopened its facility in Greater Noida, India.  Production of transmission systems.

**FINANCIAL OVERVIEW**

<table>
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<th>YEAR</th>
<th>2013</th>
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<td>401053</td>
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<td>NET PROFIT</td>
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<td>4161</td>
<td>5038</td>
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<td>EBITDA</td>
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<td>28170</td>
<td>23182</td>
</tr>
</tbody>
</table>

Note: All figures are in millions of Euros.

As of 31 December 2013, Oerlikon Graziano’s revenue was €345.6 billion (US$475.7 billion), a decrease of 9.1% from the previous fiscal year.

Net income amounted to €4.8 billion (US$6.6 billion) representing an increase of 12.5% year-on-year.

Earnings before interest, taxes, depreciation and amortization generated €2.9 billion (US$3.9 billion) marking an increase of 3.4% as compared to the previous fiscal year.

**OUTLOOK**

For 2014, Oerlikon Graziano is expecting to benefit from the positive market development in the majority of the market regions. The company projects revenue to increase by 5% and to increase R&D expenses.

The company is determined to offer various transmissions and driveline technologies to comply with more stringent emissions standards, and reduce fuel consumption and carbon-dioxide emissions.