# Final report

## 1.1 Project details

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| **Project title** | CIPED – Compact, Intelligent, Powerful Electric Drivetrain for EVs |
| **Project identification (program abbrev. and file)** | CIPED- j.nr. 64013-0565 |
| **Name of the programme which has funded the project** | EUDP 13-II |
| **Project managing company/institution (name and address)** | Insero A/S<br>Chr M Østergaards Vej 4a<br>8700 Horsens<br>Contact: Jens Christian Morell Lodberg Høj |
| **Project partners** | Aalborg University<br>ePower Technology (joined the consortium in 2015)<br>Johnson Controls, Denmark<br>Eltronic<br>ECOmove (left the consortium in 2015)<br>Future Electric (left the consortium in 2015) |
| **CVR** (central business register) | 3265 4533 |
| **Date for submission** | |

## 1.2 Short description of project objective and results

***English***

The purpose of the CIPED project was to develop a state of the art InWheel drivetrain for electric vehicles with an unmatched low undamped mass and power/weight ratio. This solution should be highly energy effective and include energy harvesting from the dampening system to increase the total range of the vehicle.

The final result of the development carried out in the project was a compact U-core 35 kW switched reluctance motor with an efficiency of +90 % over a broad range of both required torque and rpm. Further to this, an active damper system based on Magnetic Lead Screw has been developed, which has made it possible to create an intelligent dampening system, that has a positive energy output at the same time.

***Danish***

CIPED projektets formål var at udvikle en hjulmonteret drivlinje til elektriske køretøjer med en unik lav udæmpet masse og kraft/vægt forhold. Løsningen skulle endvidere være meget energieffektiv og producere yderligere energi fra støddæmperne, for at give en forøget rækkevidde af de køretøjer, hvorpå det monteredes.

Det endelige resultat af udviklingsprojektet er en kompakt U-kerne 35 kW SR motor med en effektivitet på over 90 % i et bredt spektrum af både momentbehov og hastighed. Yderligere er der blevet udviklet et aktivt støddæmper system baseret på magnetledeskrue-teknologi, hvilket har gjort det muligt at skabe et intelligent dæmpningssystem, som har en positivt energiproduktion samtidig med at den dæmper bilen.

## 1.3 Executive summary

The CIPED project was initiated to create a Compact, Intelligent, Powerful, Electric Drivetrain that could fit in the ECOmove Qbeak and be adapted to the Future Electric motorcycle. However, due to different internal events at some partners, the project experienced a turn of focus halfway through, causing the objective of the project to split in two – developing a Switched Reluctance (SR) motor for use in E-Mobility applications, and developing an active dampening system for use in all larger car categories.

The SR motor was developed in two iterations causing a prototype that in a benchmark outcompeted a Honda Civic Hybrid motor on specific parameters such as high energy efficiency at low loads and still comparable in $kW/m^3$. For a hand built prototype, this exceeded the expectations of the team and has led to positive meetings with both minor and major OEMs. During the project, the technology concept of the SR motor – a double U-core – has been awarded with a patent at AAU on which a collaboration agreement has been signed with ePower Technology.

The active dampening system was constructed on a concept of magnetic linear screw, which made it possible to design a dampening system capable of harvesting energy and providing active dampening at the same time – something that is still in concept development in the automotive industry. One prototype was built and mounted in both a test rig and a VW Passat as part of the project. The test showed an efficiency rate on the harvesting of up to 80 % and the test in the vehicle proved that the system can be controlled actively while driving. The technology is now ready for an updated design and development to be put into real driving conditions with four mounted dampers – a task which AAU is now searching for partners for.

## 1.4 Project objectives

The original purpose of the CIPED project was described as to design an InWheel drivetrain solution that was efficient on all key aspects for electric vehicles and economical viable. The solution should be a state of the art modulized drivetrain with a usage potential in several significant niches of the EV industry.

This should be achieved via reaching the following goals:

- Construction of a high fault tolerant drive train
- Optimization of motor topology and gear construction to achieve high energy efficiency over a broad user spectrum and power output (50 kW)

- Active dampening to increase driving comfort and allow for energy harvesting increasing the range of the vehicle by up to 5 %
- Development of integrated, low cost controller priced 15 % lower than competitive solutions and optimize the drive train controls
- Minimal increase in system weight
- Demonstration of an integrated solution in a vehicle test

When looking back at the project, 2 significant challenges were faced, which caused a deviation from the original targets set in the application.

The first challenge was the decision by ECOmove to leave the consortium due to internal priority and limited resources, which caused a change of focus for especially the motor development, that was then redesigned to fit the electric motorcycle of Future Electric. At this time, ePower Technology joined the consortium to fill in for ECOmove as motor producers. The project was then able to continue as planned, with the change, that the motor shouldn't fit in an InWheel system and the Damper and Motor development became to separate development tracks.

The second challenge was when Future Electric due to an internal decision by the board decided to leave the project as well. This caused the project to lose its demonstration platform, which resulted in a change to the finalization of the project, where instead a benchmark of the motor was made comparing it to relevant motors on the market, and the commercial validation was made through a direct dialogue with German OEMs to clarify if the system had validity in their portfolio in the coming years. These changes had a minor effect on the milestones, that were altered to fit the new situation and one commercial milestone was skipped. However, the project managed to meet all the identified milestones and finish within the planned timeframe with successful solutions.

The outcome of the project and work packages will be described more in depth the following section.

## 1.5 Project results and dissemination of results

### *1.5.1 Adaptive Suspension Research and Development (WP1&2)*

#### *1.5.1.1 Task description*

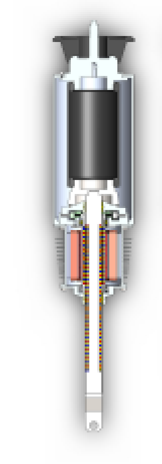
The target of the WP1 and WP2 were to create a development foundation to develop a system that would allow for intelligent and active dampening of a car. The original thought with the separation of two WP's was based on the need to first conduct research on a concept (WP1), which could then be developed afterwards (WP2). In the practical approach, it has been hard to differentiate between the two types of tasks and the reporting will therefore treat the two WP's as one.

The initial target of the WP's was to design an active dampening system, that would fit into the suspension system developed by ECOmove, but with their exit from the project, the design development was adapted to the interest, the main contributor to the WP's experienced from the Automotive industry. This had the effect, that the damper was developed to fit a car in the D segment (VW Passat, Ford Mondeo, Peugeot 508 etc.). By this time, it was also decided that the development of control systems for the damper and motor should be two independent development tracks as they would not be fitted to the same unit for demonstration.

#### *1.5.1.2 Summary of results*

A State-Of-The-Art analysis prior to the design of the damping system, showed almost no real active suspension systems for commercial use. Some researchers on the other hand have been able to construct an active system, however the lack of high efficiency, fast response, high unsprung mass or the size of the unit has been parameters which has decreased the likelihood for commercial success.
In CIPED an active damper system, which should mitigate these drawbacks has been developed and tested. The damper has been designed based on performance measured on a std.

damper unit mounted in vehicle test platform, from where it has been possible to measure both chassis and unsprung mass accelerations, together with measurements of the relative position and velocity between the chassis and unsprung mass.



The design of the CIPED damper, has been divided into the design of the MLS[1] and the custom made PMSM[2] motor. Which imply both mechanic, electric and magnetic design. Through a mathematical model of the suspension system, MLS and PMSM the energy harvesting capabilities has been tested, in order to choose the design for which it is possible to harvest the most energy from the damper system without compromising comfort nor safety.

The CIPED damper build, has been tested in a linear test bench, where it was possible to measure the efficiency of the damper at known frequency inputs. In a broad range an efficiency of 80% was measured, which was close to the simulated efficiency. The MLS of the CIPED damper was measured to have a stall force of 2600 N, which was 400 N lower than the simulated 3D model. The reason for this could be found in imperfect lead of the MLS translator/rotor, which has been glued by hand, without any zero reference for the placement of each magnets, which could add up the tolerance to a point where the stall force would decrease. However, a new translator and rotor has been order to test this hypothesis.

The CIPED damper has been mounted in vehicle (Passat B5) for real road test, however during the last weeks of the project and error in the optic fiber circuit, has limited the possible test of the CIPED damper. Therefore, the damper was connected to three power resistors which could deliver a constant damping coefficient for the CIPED damper. Test performed at the same road as was performed with the standard damper revealed a maximum mean power of 14.2 W for a cobblestone road, and 8.3 W for a road with speed bumps. The reason for this decrease in power compared with test performed with the standard damper was believed to be due to the damping coefficient being constant for the tests performed with the CIPED damper due to the nature of the load resistors.

On behalf of the above observations it can be concluded that the CIPED damper is able to harvest energy from road irregularities, and perform active control of the suspension system. However further test of the CIPED damper, will map the full potential of the unit and/or technology for energy harvesting and active suspension control.
The full report on the development and testing of the system has been attached as appendix 1 (CONFIDENTIAL).

### *1.5.2 Motor Development (WP3&4)*

#### *1.5.2.1 Task description*

As the situation with the damper development, it has been a challenge to make a clear distinction between WP3 and WP4, as the development has been overlapping. Therefore, WP3 and WP4 will be handled as one in this evaluation document

The development of the motor in CIPED is the area, which has undergone the biggest changes in the project, as the initial plan was to develop a first concept of the SR motor to validate if the concept could compete with the already developed PM motor by ECOmove. As the deadline was reached, no clear conclusion could be made and the decision between the two motors was postponed 3 months. In this time period ECOmove decided to leave the consortium due to internal reasons, which made Future Electric take over the role as demonstrator and brought ePower Technology into the consortium. At the same time, it was decided that the consortium would develop the SR motor technology to become the demonstrator for the CIPED project. As Future Electric left the consortium less than 6 months later due to a board decision, the project once again had to re-configure the work on the motor development. The

[1] Magnetic Linear Screw
[2] Permanent Magnet Synchronous Motor

decision was to continue with a slightly adapted configuration of the motor that would be comparative to the hybrid motor of a Honda Civic. It was also decided, that the demonstration of the motor would be a benchmark in a test bench, where the motor would be compared to a number of competing motors as no demonstration partner was present in the project. This work was conducted in an updated WP6.

In the last 6 months of the project, Johnson Controls decided to increase their investments in the project, as the initial results of the motor showed promising results considering their application system. This resulted in a further development project for a single phase SR motor prototype in order to evaluate its usability under certain environments relevant for JCI.

*1.5.2.2 Summary of results*

During the project, two complete prototypes where developed and produced. The first prototype was a "proof-of-concept", which served the purpose of proving that the U-core SR technology worked, and demonstrated its potential and weaknesses. From the experience gained, the design tools where improved, which allowed for the development of a new and improved prototype. The U-core concept was also altered slightly as the new "double U-core SRM" concept was made. A prototype of the double U-core SRM was developed, produced and extensively tested.

The first prototype was developed during an 8th semester student project. It was designed so that the volume of the cylinder enveloping the stator of the PMSM utilised in ECOmoves Qwheel, would be the same volume of the cylinder enveloping the stator of the U-core SRM. During development, the magnetic circuit was optimised through a sensitivity analysis of parameters. The mechanical design was made with focus on function over form or weight – the prototype should be manufactured in a short period of time, and most important of all, it should work. Therefore, neither the technical solutions nor the weight of the mechanical structure was optimised. The result was a very heavy and bulky prototype, however, it worked, and demonstrated the advantages and disadvantages of the technology, as intended.

Three students decided to continue and do a long master thesis, working on the U-core SRM during their 9th and 10th semester. During the 9th semester the first prototype was extensively tested to map its performance in most of the intended operating area. It was found that the motor performed significantly worse than expected. This was caused by two things; the dynamic models were not sufficiently accurate and the technology had several unexpected phenomena causing undesired losses. Furthermore, the development of the prototyped revealed a number of disadvantages of the technology; it had a lot of excessive end windings due to the full-pitch winding topology, and there were excessive losses in the wedges between segments and housing of the SRM due to flux dispersion. From the tests it was found that core losses were much higher than expected; partially due to the laminations deviating from the data sheets and partially due to excessive losses in surrounding components. It was also found that the static torque of the machine was 12 % lower than expected, due to 3D effects.

The results obtained were utilised to improve on the design tools and the topology. This meant that a new prototype could be developed during the students 10th semester project. The design tools were further improved by a number of initiatives. The computation time of the models were reduced significantly by making a simplified dynamic model and by improving on the magnetostatic FE model. By utilising COMSOL instead of FEMM, the mesh could be much better optimised for the geometry, which significantly reduced computation time. Furthermore, a method was proposed to correct the results from the 2D FE model for 3D effects. The model of the mechanical losses was also improved to include a model of bearings as well as a model for both salient and cylindrical rotors. Core losses were corrected by considering the difference between data sheet and measured values. Finally, a thermal model of the machine was setup.

A new concept was presented, that further developed on the U-core technology – called the "double U-core SRM". The double U-core SRM consists of segments made of two U-cores each, connected by a bridge. This concept eliminates the full pitch windings, which significantly reduces the excessive amount of end windings. This means the copper is much better utilised. A new prototype was developed through a comprehensive process, where magnetic, electrical and mechanical aspects were considered. The magnetic circuit was optimised to maximise efficiency in the important parts of the operating area. The number of turns of the coils was chosen to get the most out of the supplied voltage. Finally, an advanced mechanical structure was made, where concrete was cast between each double U-core segment, and a crimp ring was used as housing, resulting in a pre-tensioned stator structure, providing great stiffness. Finally, the design was verified by using the previous mentioned thermal model.

### *1.5.3 Controller Development (WP5)*

#### *1.5.3.1 Task description*

The target of WP5 was originally to develop an integrated controller for a InWheel motor.

The controller was specified by ECOmove to fit into their wishes for a InWheel motor. After approval of their specification the design was made. It was a wish from ECOmove that the design was based on integrated IGBT modules. These module gives a very efficient thermal design but leaks from their higher unit price compared to a design based on discrete components. At the time when the design was ready for review ECOmove decided to leave the consortium due to internal reasons.

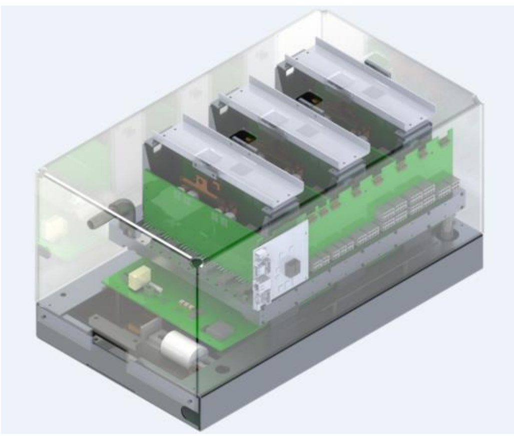
With the exit of ECOmove a new demonstrator was found in Future Electric and the goal changed from InWheel controller to a controller that would fit into an electric motorbike. The process of creating new specifications was started and again the design was based on using integrated IGBT modules. At the time when the specifications were approved and part of the design was already made Future Electric left the consortium due to a board decision.

With the exit of Future Electric the demonstration platform disappeared. With respect to the knowledge gained in both motor and controller development it was decided to turn the outcome of the project against a benchmark platform. The controller were designed to be modular and universal unit with the possibility to adapt to different motors. The integrated IGBT modules were dropped and a design with discrete IGBT's in parallel was made. During this redesign the entering of ePower was very useful as the new design was inspired by their practical knowledge about SR drivers. The resulting controller was a unit based on a Bus Bar where up to 6 segment boards could be installed. The heart of the unit is the controller board on which the FPGA board is installed.

#### *1.5.3.2 Summary of results*

The controller was made in a modular way and consists of the following units:

- Bus Bar, PCB
- Segment, PCB
- Interface, PCB
- sbRIO, PCB with FPGA
- Water cooled heat sink



A complete prototype was manufactured and used during the benchmark test. During the design of the prototype a lot practical problems was identified. Most of the problems were related to the high current and the need for sufficient cooling.

The first practical problem was to design the output stage of the driver in a way that it could handle high current up to 500 A rms and 1000 A peak. The solution was 6 IGBT's in parallel for both HI- and LO-side switch per segment giving a total of 72 IGBT's.

Another practical problem was to design the heat sink for the system. The number of components to handle (72 IGBT's) and heat to transfer wasn't an easy task to solve. The result was a cleverly build water cooled heat sink which turned out to be a very efficiently. Also, finding a good insulation pad to use between power components and heat sink has required a good amount of research and experimental validation

To handle the high current internally on the PCB's it was decided to visit a PCB manufacturer. The visit was planned in the hope that theory and practical possibilities would join up. The conclusion was that the cupper thickness was changed from the standard 35u to 210u. In practice, it turned out to be a big challenge for the PCB manufacturer but after a few experiments they succeeded to produce the boards.

The different secondary functions on the board were tested. To highlight a few, it was observed that the high-speed resolver interface functioned as planned as well as the individual current measurement, one for every phase, was reliable.

During the benchmark test the controller was tested as a complete unit. The unit was tested up to 40 kW at 330VDC for 20 seconds. The test was stopped to save the motor not the controller. No critical temperature rise was detected and it is expected that the controller is able to handle even higher power for longer time.

The production documentation (BOM and GERBER files) was handed over to an EMS located in Asia. The availability of the chosen components was tested and an evaluation the producibility was evaluated. The result was a production price that was about 15-20% lower than comparable controllers.

### *1.5.4 Technical validation of CIPED solutions (WP6)*

#### *1.5.4.1 Task description*

*WP6 vision for technical validation of CIPED motor (benchmark of motors):*
To finalise and validate the mathematical models using results from the second prototype, to be able to use the models for designing new machines.
To test and map a number of machines utilising competing technologies, to identify unique strengths and relevant applications of the technology.

*WP6 vision for technical validation of suspension solution (real vehicle test):*
To develop the suspension solution to a level, where it will be possible to test the energy harvesting and dampening solution in a real vehicle, with two mounted prototypes.

#### *1.5.4.2 Summary of results*

*Benchmark of motors:*
The prototype of the double U-core SRM was comprehensively tested and assessed. During assembly, core loss was measured in different configurations, to be able to assess the impact of each of the surrounding components (distribution rings, jacket, etc.). It was found that the distribution rings did not add excessively to the core loss, and they could even be made from aluminium without suffering. The jacket however was found to increase the core loss slightly when made from aluminium, hence it should be considered to make it from stainless steel in the future. Finally, it was confirmed that the spacers between the double U-core segments should be made from non-conducting and non-magnetic material if possible.

Thermal tests were made both with the naked segments, as well as the segments placed in the distribution rings and finally the complete assembled machine. The resistance and inductance of the coils were measured and found to match satisfactorily with the modelled values. The mechanical losses were measured using retardation tests. By using a recommended run-in procedure the losses of the bearings was reduced significantly, resulting in a halving of the total mechanical loss. The acoustic noise of the machine was mapped and it was found that it is excessively loud. Therefore, efforts should be made to reduce the noise level in the future. Finally, the static torque of the machine was measured, and it was found that the prototype delivered a slightly higher torque than expected, meaning that the proposed 3D effect correction performed satisfactorily.

After all of the minor tests were performed, the machine was put in a test bench to measure its performance in the complete operating area. The motor unit from a Toyota Camry Hybrid car was used to load the machine. The drive used to run the Camry motor limited the operating area that could be tested. Therefore, tests are only performed up 6000 rpm and 70 Nm. During the loaded tests, it was found that the measured efficiency of the double U-core SRM was higher than expected, hence the machine performed very satisfactorily. Comparing the measurements to the model, it was found that there were a number of causes to the slight deviation. The modelled resistance was slightly higher than the actual resistance. The mechanical losses were measured to be slightly higher than expected, but as they are very small, it does not impact the total losses much. In the model, core losses were corrected using measurements from the first prototype. This resulted in higher expected core losses than what was measured. Finally, the torque curves used in the model was slightly lower than measured.

By correcting the coil resistance, using measurements from a solenoid to correct core losses and implement flux linkage and torque curves from a model where the air gap was reduced to 0.43 mm, which was measured on the prototype, the modelled results corresponded much better to the measured. To sum up, it is found that the model and design tool that it makes up performs satisfactorily, as the results regarding efficiency is within 2 percentage point in the loaded tests over a broad area of the map. There are not any major concerns that should be addressed to improve on the model.

In extension to the loaded tests, the results were compared to competing technologies through a benchmark of the double U-core SRM. In the benchmark, the double U-core SRM is compared to three PM machines; an EMRAX 208 axial flux machine, a Toyota Camry PMSM and a Honda Accord PMSM. It is found that the PM machines have a higher air gap shear stress, resulting in higher torque density and power density. Considering the active material it is found that the SRM has almost comparable specific power to the Camry and Honda motors. Considering the copper loss, the SRM has a higher copper loss and it is found that it is the hardest driven machine, with a very high copper loss at maximum torque. However, the double U-core SRM has a great efficiency at high speed/low torque compared to the other machines, which also gives a great advantage when free-wheeling. This can also be seen when comparing the idle losses of the machines.

In general, the double U-core SRM has an advantage when considering the reliability and fault tolerance of the machines. Furthermore, it is an advantage that it does not use any rare earth materials. The segmented stator and compact end windings limits the used amount of materials.

In extension to the benchmark against competing technologies, a comparison is also made to two regular SRMs. Here a 1-phase 8/8 regular SRM is compared to a 1-phase 8/8 double U-core SRM. Here it is found that the two machines have similar performance. The double U-core SRM has lower copper loss whilst the regular SRM has lower core loss. It is found, that the double U-core SRM has lower total loss when considering machines with a certain stack length. The double U-core SRM is also compared to a state-of-the-art SRM, Chiba's 18/12 SRM. Here it is found that when using the same laminations, the efficiency of the double U-core SRM is competitive to Chiba's SRM. The double U-core SRM has a higher efficiency at high speed/low torque and a high efficiency in a broader span than Chiba's SRM. However, Chiba's SRM has a much higher torque and power density compared to the double U-core SRM.

As a last remark, it is found that one of the main caveats of the double U-core SRM is its cooling system. This also limits its torque and power density. Therefore, efforts should be made to improve on this in the future.

*Real vehicle test:*
See previous section 1.5.1.2.

### *1.5.5 Commercial validation of CIPED solutions (WP7)*

#### *1.5.5.1 Task description*

WP7 was reformulated as part of kick-off 3.0 (Future Electric withdrawal) – thereby concerning a commercial validation of the developed CIPED solutions, in which the market and potential customers of the two CIPED technologies should be investigated.

#### *1.5.5.2 Summary of results*

Two market analyses were made: Market analysis of the CIPED Motor and market analysis of the CIPED Damper. With completion of these market analyses, the project has successfully obtained CM4 (Commercial Milestone 4).
The underlying purpose of both analyses were to investigate the market potential of the project technologies – what is the value proposition, which markets to target, who are the customers, are market barriers high/low and how to deal with them? The sum of these constitutes a more deliberate foundation for a potential Go-to-Market strategy.

Each analysis followed a process and method design starting with an initial market delimitation (based roughly on a technology value proposition), followed by a definition of segment evaluation criteria, data gathering combined by desk research and expert interviews, analysis and discussion consolidated in report format. The process and findings can be found in two separate reports, including final recommendations. Highligts are presented below.

*Highlights from market analysis for CIPED motor*
To investigate the market potential of the CIPED motor, Insero conducted in-depth screening of the conveyor, air-condition and indoor crane segments.

Overall, it is seen that the different markets in which electric motors including CIPED potentially could be applied seem highly fragmented and specialized, as each use case seems to have unique motor requirements.

Hence, there seems to be a significant market potential for the CIPED motor across several applications and segments, as it features as the best motor among the current variable speed drive systems within the market and can be built for applications with power requirements ranging from 5-200 kW, which is a wide range of applications. The only major drawback of the CIPED motor is the maturity of the Switched Reluctance technology, which according to Nidec Motor Corporation is in its infancy. To exploit the full market potential of the motor, CIPED should offer it in a flexible setup, which enable it to be produced and installed according to the specific requirements of i.e. an industrial conveyor belt or elevator crane. Furthermore, CIPED could potentially benefit from engaging in a partnership with one of the main producers of elevators and conveyors, as they, presumably, could help the company to develop motors that match the typical requirements within the segments, and establish a solid knowledge base of motor application and requirements within the specific industries.

*Market analysis of the CIPED Damper*
In this analysis, Insero emphasized the automotive market, and more specifically the M1 segment, which is the standard car segment. This market has a strong correlation with the

features of the CIPED damper, and contains an enormous economic potential, if CIPED could successfully penetrate the market.

The M1 segment was sub-segmented in 8 categories, which was further evaluated based on ten different criteria, which ideally ensures that the resulting conclusions are valid and reliable. The criteria chosen for the analysis were price of the car, type of standard damper installed, possible suspension upgrades, focus on safety, focus on environment, focus on comfort, durability, fuel consumption, typical driving pattern within the car segment, and the segment's ability to store and use the energy that the CIPED damper can harvest. In addition to these criteria, Insero have consulted specialists at respectively Triscan and Tenneco, who have evaluated the potential of each segment, and provided insights into the competitive situation and value chain within the automotive market.

It is evident that there are highly favorable markets to pursue, but these have similar high market barriers. One way to go is the market for high-end BEV (Battery Electric Vehicles) such as Tesla, as they use advanced technologies, which are fully compatible with the energy harvesting features of the CIPED damper. Furthermore, Tesla is an organic organization that constantly searches for new ways to innovate and disrupt the automotive sector, which could potentially lead to their interest in adopting a new technology such as CIPED. This is one path to take – other alternative ways to go could be to sell technology, or sell the product through i.e. Tenneco, Küpp or Sachs, which are dominant players within supply of suspension systems and dampers to the majority of OEMs.

### *1.5.6 Project Management and Dissemination (WP0)*

#### *1.5.6.1 Task description*

This task covers project management including coordination of steering committee meetings and summaries, the half yearly reporting and ensuring that the project is proceeding according to plan and budget. Included is also the dissemination of the project.

#### *1.5.6.2 Summary of results*

*Project Management*

Project Management and monitoring of progress in the project has been maintained in weekly progress meetings via conference calls. Every 6 months, physical project meetings and steering group meetings were held at partners' facilities. Extraordinary partner meetings have been held as part of kick-off 2.0 (ECOmove withdrawal) and kick-off 3.0 (Future Electric withdrawal).

*Dissemination*

The project launched a project website in the beginning of the project. The website has been useful as redirection point in terms of all external contacts, and there have continuously been inquires – particularly in the last phase of the project, when technical results were presented. A project video was developed and presented as part of the final project meeting in December 2016 and has been shared via the CIPED website and the Insero LinkedIn and Facebook profiles.

A number of papers and newspaper articles was published in the project period, including:

- Technical-academic article about the magnetic led screw in the IEEE Xplore Digital Library (link)
- One of the largest Danish newspapers – Jyllands-Posten – wrote and printed an article in their financial sector (link)
- A Press Release was sent out in July 2016, which led to an article in Ingeniøren – a well-recognized national technical newspaper. The article was published November, 2016 (link)
- The project published a second Press Release at the end of the project, in January 2017.

CIPED was presented at a number of events. Highlights are:

- The Danfoss Award "Engineering Tomorrow", April 2016
- Energy Conversion & Exposition (ECCE) – world leading conference within electrical systems and energy conversions, held in Milwaukee, WI, US, September 2016
- Event at Dansk Magnetisk Forening (Danish Magnetic Association), November 2016

After kick-off 3.0 (Future Electric withdrawal), the consortium agreed to put more direct focus on dissemination towards potential OEM cooperation. Insero planned a week of travelling around Germany to visit relevant OEMs in November 2016. The tour started with a full schedule of meetings, but with change of plans along the way. Some scheduled meetings were converted to phone/skype meetings instead.
Altogether, the tour was time well spent, with good feedback on the CIPED technologies/solutions and relevant input and learnings from the companies. One main learning was the transition towards solutions without use of Rare Earth Materials, which was mentioned as a vital strategic item on the automotive industry agenda. In particular, the meeting with VW was promising. They were very interested in hearing more about both the CIPED motor and damper. Follow up contact and dialogue were established after the meeting.

Based on the OEM meetings, the project has successfully obtained Commercial Milestone 1 (CM1), where target said: "Presentation of technical solution for a group of stakeholders (min. 5 companies)".

Furthermore, the project developed a product spec sheet for the CIPED motor, which was the target of the Commercial Milestone 3 (CM3). This was ready in November 2016, which was excellent timing in terms of CIPED partners' important stakeholder meetings in that period.

### 1.6 Utilization of project results

Now that the project has finished and the results have been disseminated, the consortium has continued the collaboration to secure a foundation in each of the organizations with the interest. Conclusions from the consortium are:

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| ePower Technology: | The motor has become a central part of the organization's portfolio and currently reacting to several RFQ[3]'s from international and national vehicle producers. A specific business plan for the technology has been developed based on the market analysis conducted in the project. |
| AAU: | Continues to research in the SR technology and the active damper technology with partners from CIPED and externally. AAU has during the project patented the technology and a collaboration agreement with ePower Technology has been signed. |
| Johnson Controls: | Setting up student project with spin off motor from the CIPED project. |
| Eltronic: | Will not be pursuing the controller unit further, as they have made a strategic decision on not having products in their portfolio. |
| Insero: | Expecting to publish a new knowledge product based on the lessons learned from the CIPED project. |
| ECOmove: | In the meantime, ECOmove has been sold to China and has no interest in the CIPED conclusions. |
| Future Electric: | Future Electric (now Fenris) has no current interest in the motor before the power/weight ratio increases. |

[3] Request for Quotation – often sent by OEMs to potential subsuppliers

In conclusion, the project has created a positive impact on four of the seven involved companies and the results will be carried into commercialization by ePower Technology now and potentially later result in a product for Johnson Controls.

## 1.7 Project conclusion and perspective

When looking at the results from the CIPED project, several conclusions are seen from both technical and business viewpoints:

- A Switched Reluctance motor can provide competitive solutions to PM motors in markets where robustness and high fault tolerance are important
- The motor has a perspective to become price competitive when a high production number can be reached and is less sensitive towards price deviations due to the lack of rare earth materials
- A digital modelling tool has been constructed to help design motors to fit specific demands by new customers
- It is possible to construct an active dampening system for cars that can provide both intelligent dampening and harvest energy
- At least one large car manufacturer has claimed that they have a strategic target of producing rare-earth material free motors in the future and a dialogue with this OEM is ongoing
- Several OEMs are looking into active dampening as a future service and dialogue is ongoing between AAU and one of these
- New markets could be relevant to explore further to see if production volume could be increased, and will be approached by ePower Technology in 2017.