Management of innovative technology of Elaphe* "in-wheel" electric motors - a case study

G. Lampič[1], A. Detela[2] and J. Valentinčič[3]

[1] *Elaphe d.o.o., Slovenia*
[2] *Jožef Stefan Institute, Slovenia*
[3] *University of Ljubljana, Faculty of Mechanical Engineering, Slovenia*

Abstract

Electric vehicles such as bicycles, scooters, even cars, are becoming more and more popular. The most convenient and advanced propulsion system for such vehicles is based on direct drive (DD) motors, where electric motor is mounted directly into the rib of driving wheels. Thus, they are also called in-wheel motors. The most important characteristic of such motors is specific torque, i.e. motor peak torque over motor mass. Electric motors of the Elaphe* series achieve specific torque of over 30 Nm/kg which classifies them among the best DD motors. This paper presents the R&D background and management of the Elaphe* series motors. The goal of the project is to push the innovation into next generations of cars in the automotive industry by keeping all the intellectual rights over the innovation. Thus, a thoughtful management is crucial for overall success of the project.

Keywords: Management of innovative technologies, in-wheel electric motors, direct drive, industrialisation, case study

1 Introduction

The idea of electric vehicles is relatively old and some successful prototypes have already been presented in the 50's [1], but due to several reasons such vehicles are still not widely used. Now it looks like the time for such vehicles is straight ahead of us. Every serious car manufacturing company has an alternative solution of propulsion systems [2] as well as an electrically driven prototype. The only acceptable propulsion system is based on DD motors, also called in-wheel motors, but there are still unsolved technical challenges in order to successfully implement this idea into reality. Such propulsion systems are becoming more and more used in electric bicycles [3], electric scooters [4], ultralight airplanes [5], etc.

Some years ago our first generation of synchronous "in-wheel" electric motors was invented and protected by a series of patents [6,7,8,9,10]. These motors are able to control more than 8 million positions per rotation (revolving precision of 23 bits, which means 0,15 arc-sec of revolution), achieving torque of 15 Nm and rotation speed 160 min^{-1} [11]. The patents, together with technical assistance, were bought by the Japanese company Harmonic Drive Systems (HDS). Together (HDS and Detela) they realized the ideas and now HDS is manufacturing and selling these motors under the name "KDU series" (Kobayashi - Detela Unit) as given in Figure 1. Such motors are used in high-end robots (they are at the very top in its class of requirements) and the market price of these motors is in the range of 5000 US $.

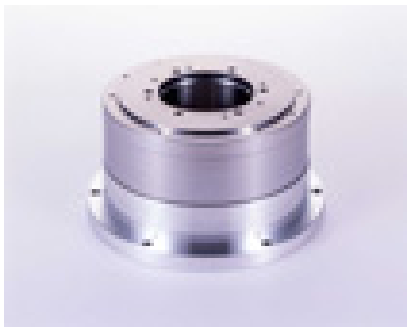


Figure 1 Materialization of innovation: Harmonic Drive Systems introduced new series of DD motors called KDU (Kobayashi-Detela Unit) [11].

Based on knowledge gained through KDU industrialization, a new generation of DD motors named Elaphe* was invented, and a company with the same name was established in October 2006. The task of this company is to push the Elaphe* motors into mass production – meant for the next generation of electric and hybrid vehicles. For successful industrialization an informal consortium of more then ten companies and institutions has been established. The goal of the management is to

make sure, that the innovation will find its place in the industry and in the market at appropriate time.

The Elaphe project is growing in parallel on the material and on the immaterial level, both of them being of crucial importance and mainly interconnected. This paper is structured in this manner just as well.

In the first part, we describe and present an apparently "linear" materialization of our innovative designs, from our first prototype motor up to the third generation of prototypes. These prototypes were designed for use in electric scooters and in an ultralight electrically-powered glider.

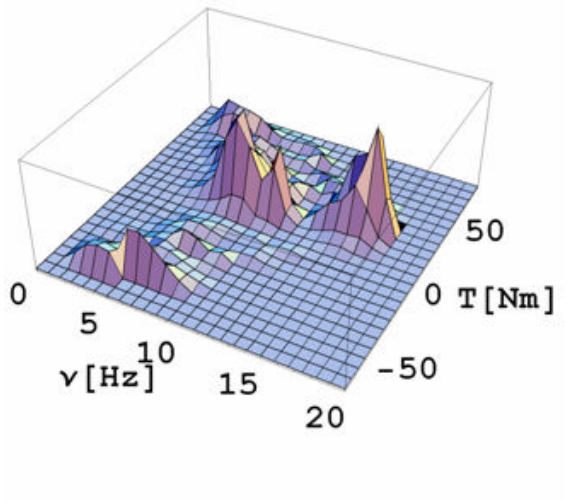
In the second part, we emphasize some of the most crucial events and some of the most interesting and challenging questions, as well as solutions. Project-leading and decision-making may be even more demanding then the development work itself. But dealing with real problems of our modern world and trying to solve the most important ecological problems of the modern society motivates the majority of our accompanying activities, like an invisible "motor" on the immaterial level.

2 Material level

Successfully completed project (in cooperation with HDS company) of high-tech DD motors for robots has been a good base for an ambitious project of industrializing even more advanced electric motor construction here, in Slovenia.

Andrej Detela has designed the basic construction of the Elaphe* electric motors and derived a mathematical model predicting the motor characteristics. These motors are designed to fit into the wheel rim and must satisfy very strict technical demands. Based on available data, they are among the best in the world.

The mathematical model was upgraded to detailed analytical/numerical simulation of the motor behavior, with regard to specific vehicle application (Figure 2). The simulation was developed in Wolfram Mathematica environment and it radically accelerated the design process of the Elaphe* motors.



Our first prototype (Elaphe*1, see Figure 3) was designed to satisfy the requirements for a light electric two-wheeler (bicycle or scooter) and was manufactured to test the mathematical model. Results of the measurements were in agreement with our calculations. The second prototype Elaphe*2 (see Figure 4) was designed for direct-drive propulsion system of a urban car. A variety of manufacturing improvements were introduced, specially in manufacturing of vital parts such as coils, etc.

Figure 2 Energy consumption in speed-torque space

Figure 3 Prototype Elaphe*1

Figure 4 Prototype Elaphe 2

The final test of motor performance lies in its real application. Now prototypes for two specific applications are in the closing stage of manufacturing: the first type is for electric scooters and the second is for ultralight electrically-powered glider driven by electric DD motor.

Figure 5 3-D drawing of the prototype Elaphe*3

Figure 6 Prototype Elaphe*3

Figure 7 Elaphe*ET for Electro Taurus ultralight powered glider

The motor for the world's first ultralight electrically-powered glider with two side-by-side seats was designed and produced for the glider Taurus of Pipistrel company (Figure 7) [12] .

Elaphe team invented the basic concept of the Elaphe* motors, carried out mathematical models, technical drawings and full technical assistance during the manufacturing of prototypes. Figure 5 shows the 3-D drawing of the prototype Elaphe*3, of which the casing forms a part of the rear wheel in an electric scooter. The manufactured prototype Elaphe *3 is shown in Figure 6.

3 Immaterial level

So far, we have presented the material results of our project. In the following part, we want to describe the immaterial aspect of work, things we have learned and questioned.

The immaterial progress is not linear. It consists more of the questions then of detailed answers. Quality of decisions is rarely measurable; level of uncertainty is very high.

3.1 Developing the idea, "defining" our vision

We believe that scientific skills, material resources and time should be invested only in projects that will significantly benefit humanity with "real" (genuine) added value.

During our working process we have realized more in detail what we are capable and motivated to do. The basic ideas had to be upgraded with regard to the specific technological and economical environment.

The starting idea was confined only to design electric motors and thus to support the industry that will produce and sell them. However, due to large advances from previous technological solutions we have to be involved also in other areas like:

- marketing (searching for potential customers)
- promotion and education (explaining the technological and economical aspects to potential partners)
- prototype production (coordinating partners, including in-house production)
- energy source basic research (fuel cell technologies, advanced batteries …)
- basic research in electronics (electric gears, electric controllers)
- expertise support to the government

In order to successfully realize our vision, we had accepted other challenges and it is day-to-day questioning how far it is worth to invest our time, energy and money in other research activities.

3.2 Inventing the business model

Our purpose is to bring new ideas into life and so we had to develop a working business strategy to finance R&D. Since our development program is innovative we had do design also an innovative business model that fits to the nature of our project and to the characters of all involved people.

We have set and ignited the R&D – production – market triangle (Figure 8 and 9).

3.3 The team

People are the most crucial element of the whole project. The Elaphe team is organically growing and experts from different areas are joining in. Everybody in the team is self-motivated.

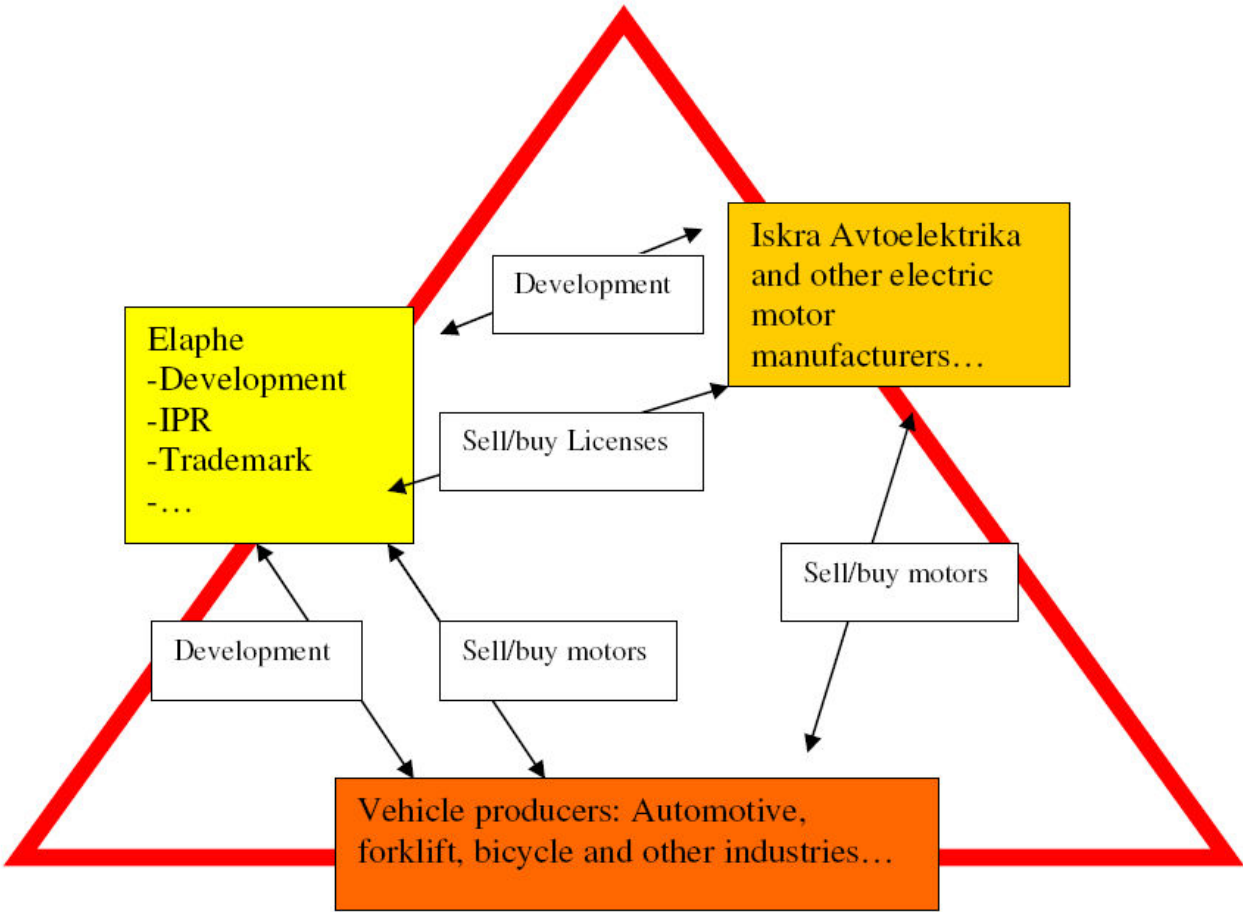


Figure 8 A triangular business model arrangement, since Elaphe is cooperating with partners from electro industry and vehicular industry.

3.4 Leading the team

Our core team is, like many other start-up teams, horizontally organized with no formal leadership. Everybody takes care of his area and all of the time we know what other members are doing. We communicate a lot and this is good and necessary since even the executive work is interdisciplinary.

Perhaps the most important concept in managing the project is learning by doing. Some knowledge can be learned from books [13,14,15] or seminars but it is crucial that it is tested and analyzed in practice.

3.5 Coping with dilemmas

We are coping with many dilemmas and we believe that sometimes it is even more important to think about them then to select the best alternative. Decisions often have to be made quickly and most of them are not irreversible. In development we try to stay flexible and always opened to new opportunities. It is also in the interest of our partners to have a successful partnerships.

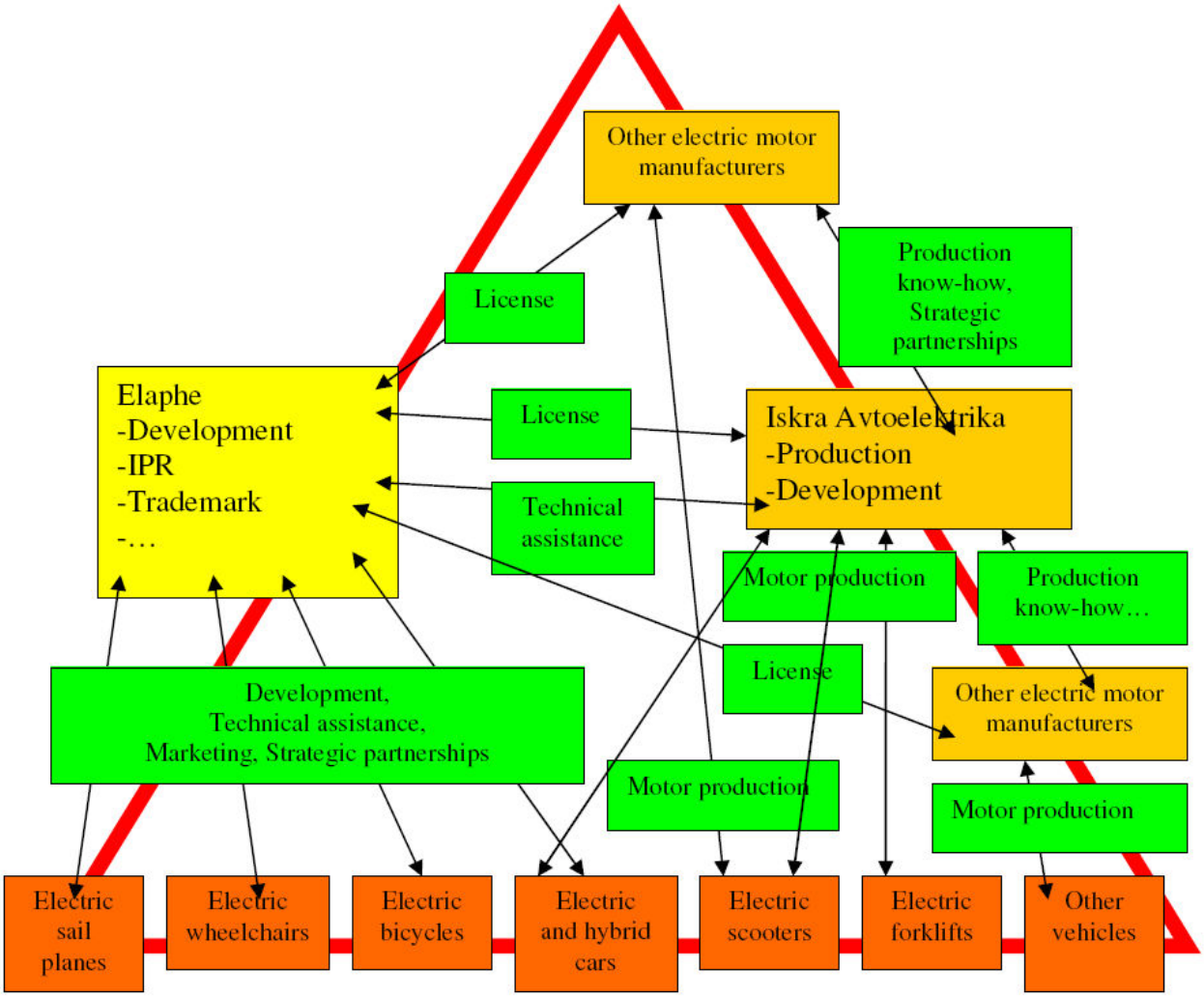


Figure 9 A triangular business model arrangement, since Elaphe is cooperating with partners from electro industry and vehicular industry.

3.6 Push the development - make the living dilemma

It is obvious, R&D is our core business, but we also have to live out of something. Our solution to this dilemma is to sell R&D as produced prototypes. It is working well in the case of electric sailplane project where we made a deal with our customer by selling the prototype which we had to develop also from the R&D aspect.

3.7 Networking – working dilemma

How much time and effort should we spend in networking and how to still stay focused on R&D? The solution is to combine networking with other social activities and education.
It is working well since there are many networking events prepared by entrepreneurship promoting institutions like Technology Park, Incubator, YES, CEED and other institutions.

3.8 Organic growth – Venture Capital dilemma

Venture Capital (VC) founds are very popular in start-up business. Since we have won few awards for business plans some of the development activities are funded from these awards. We have been invited by few VC founds and business angels and we were negotiating possible cooperation.
What we have learned is that a perspective start-up company can learn a lot from considering cooperation with VC founds, but has to be very particular when deciding for real cooperation. In our opinion VC should strengthen the weakest area of start-up company, but unfortunately we have not found even one compatible with our needs yet. It seems also true that if one organizes the company in a way VCs requires for an investment, he is most probably on a good way to make successful

business. But in this case he doesn't even need VC investment. We are using this method and we think it works well, however, we are searching for appropriate VC for a strategic partnership.

3.9 Promotion – hiding dilemma

When involved in high tech R&D the intellectual property is of crucial importance. We use a strategy to promote know-how that others can clearly understand. The most advanced and deepest know-how is not required for promotion. We also express our confidence by showing our knowledge; it is a good way to make new partnerships. It also has to be emphasized that ideas are not worth as much as their realizations in these days.

Additional reason to discuss our R&D is also our vision to accelerate the growth of electric propulsions and we are aware that we can not do it on our own.

3.10 Home – abroad dilemma

Where is the playground? The world is flat and there are at least three interesting options:

- Slovenia, where everything is nearby and skills are on the top level.
- The developed west or Japan with good skills and powerful industries.
- Asia with low production price, and ambitions to grow.

Our main motivation was to do as much as possible in Slovenia, but we found the culture is not prepared to support the most ambitious projects. The Elaphe project will most likely proceed in the following way: Prototype production in Slovenia, R&D in cooperation with developed countries and Asia, industrialization in Asia.

4 Conclusions

What is what we are doing? Is it business, science, sport, culture, game or something else? Well it is all of that.

References

[1] http://www.britishpathe.com/images//preview/00000000/00056000/00056320.WMV (18.9.2007)

[2] http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/ld_fc_vehicles.pdf (18.9.2007)

[3] http://www.electric-bikes.com/ (18.9.2007)

[4] http://www.evtworld.com/ (18.9.2007)

[5] http://www.aeroconversions.com/e-flight/ (18.9.2007)

[6] DETELA, Andrej. Hybrid synchronous machine with transverse magnetic flux : USA patent no. 5712521. [S.l.: s. n.], 1998. http://v3.espacenet.com/family?DB=EPODOC&IDX=AU2002314701&F=8&OREQ=0&textdoc=TRUE. [COBISS.SI-ID 13095463]

[7] DETELA, Andrej. Sinhronski hibridni električni stroj s toroidnim navitjem : patent, SI20497. Ljubljana: Urad Republike Slovenije za intelektualno lastnino, 2001. http://v3.espacenet.com/family?DB=EPODOC&IDX=SI20497&F=8&OREQ=1&textdoc=TRUE. [COBISS.SI-ID 15732263]

[8] DETELA, Andrej, YOKOZAWA, Shiro. Hybrid synchronous electronic machine : patent, WO03007459. 2005; [S. l.: s. n.]. http://v3.espacenet.com/family?DB=EPODOC&IDX=WO03007459&F=8&OREQ=1&textdoc=TRUE. [COBISS.SI-ID 19229223]

[9] DETELA, Andrej, YOKOZAWA, Shiro. Hybrid synchronous motor equipped with annular winding : patent no. WO0152388. 2005; [S. l.: s. n.]. http://v3.espacenet.com/family?DB=EPODOC&IDX=WO0152388&F=8&OREQ=1&textdoc=TRUE. [COBISS.SI-ID 19229479]

[10] DETELA, Andrej. An integrated position resolver for hybrid synchronous electric motors : patent, WO03005530. 2005; [S. l.: s. n.]. http://v3.espacenet.com/family?DB=EPODOC&IDX=WO03005530&F=8&OREQ=1&textdoc=TRUE. [COBISS.SI-ID 19229735]

[11] http://www.hds.co.jp/HDS_hp_english/english/products/ddm/kdu/index.html (18.9.2007)

[12] http://www.pipistrel.si/ (19.9.2007)

[13] D. Zohar, I. Marshall: **Duhovni kapital**, Tozd 2006

[14] M.H. Bazerman, M.A. Neal: **Negotiating Rationaly**, The Free Press 1992.

[15] M. Musashi, **Knjiga petih prstanov**, Amalietti, 1997.