FFI

Innovative and lean production of Transmission parts

Project within: Sustainable manufacturing

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Date:130131

Content

FFI in short

FFI is a partnership between the Swedish government and automotive industry for joint funding of research, innovation and development concentrating on Climate & Environment and Safety. FFI has R&D activities worth approx. €100 million per year, of which half is governmental funding. The background to the investment is that development within road transportation and Swedish automotive industry has big impact for growth. FFI will contribute to the following main goals: Reducing the environmental impact of transport, reducing the number killed and injured in traffic and Strengthening international competitiveness. Currently there are five collaboration programs: **Vehicle Development, Transport Efficiency, Vehicle and Traffic Safety, Energy & Environment and Sustainable Production Technology.**

FFI

For more information: www.vinnova.se/ffi

1. Executive summary

The project is mainly addressed to manufacturing of components and sustainable production engineering. Production engineering is one of 9 prioritized specializations within FFI.
The main goal with this project has been to show the advantages and possibilities with gear made with powder metal technology (PM) compared to conventional manufactured gears from forged steel.
At start of the project 5 main activities were planned. All activities are fulfilled and they show good possibilities for P?M-gears as for example lower material and part cost, less energy consumption in production, reduced weight of component which also will reduce fuel consumption in vehicle. PM will also provide new design possibilities.
The picture on front page is a gearbox for electrical cars which is originally designed with conventional machined and case hardened gears by Vicura . Vicura has a part of this project reengineered it with PM-gears. The prototypes Are manufactured by Swepart Transmission with blanks from Höganäs AB

1. End users have been visited and presentations have been made at beginning and during the project for example at the yearly FFI conference in Katrineholm.
The knowledge about PM has increased as a result of the project and the potential with PM-gears have been visualized which has increased the interest for PM gears.
2. A conventional gearbox for a small car and a gear box for electrical cars originally designed with conventional machined and hardened steel gears have been reengineered for PM gears to show that PM-gears in many applications can replace conventional gears. Some prototype gear boxes have been manufactured with successful result.
3. Conventional gears in a rally car has been replaced has been replaced by PM-gears to show that PM will work also in very demanding application. Item 2 and 3 shows that PM can replace conventional gears in high loaded applications as engines and gearboxes.
4. Both spur and helical gears have been compacted, sintered, hardened and machined with good result. We have found that some PM-qualities require different properties on the cutting tools compared to forged steel if they need to been machined before hardening. The wear of the cutting tool is increased but there is no problem with chip breaking.
We have also found that the heat distortion is considerably less for PM-gears compared to gears from forging. This is a big advantage especially for thin section ring gears.

5. Product cost calculations are made for a number of different gears and the cost for PM-gears have a potential to be up to 30% cheaper compared to conventional machined gears from forged steel. In general the saving will increase for more complex geometries.
We have in this project studied both engine gears and gears for manual transmissions and hybrid vehicles. Without strengthening methods as surface rolling or Hipping (Hot Isostatic Pressing) about half number of the studied gears can be made by PM technology.
Less heat distortion and better damping properties for PM-gears can be advantageous especially for electrical and hybrid applications where low noise is extremely important.

We have in this project showed that PM-gears in many applications are a competitive alternative both technically and costly compared to conventional machined and hardened gears from forged steel.
The interest from the automotive industry has increased during the project and we have received a number of inquiries for prototype gears made in PM.
Material tests, S/N-curves, is a time consuming but ongoing work. To be able to design PM-gears it is absolutely necessary to have available material data.
Missing material data and design rules together with lack of experience for design with PM is limiting factor for introduction of PM-gears. There are also no production facilities available for manufacturing of large volumes of PM-gears.
However, this project has shown a bright future for PM-gears.

2. Background

Höganäs AB have developed different metal powder mixes with mechanical properties getting closer to steel. The industry have been using PM-gears for many years in low loaded applications as handhold electrical machines and gardening equipment.
With new improved powder mixes and new manufacturing techniques it is possible to use PM-gears also in high loaded application as engine gears and for gears in gear boxes for vehicles.
SwePart Transmission and Höganäs AB have cooperated to manufacture PM-gears for different automotive gear boxes to replace conventional machined and case hardened gears from forging.
The trials have been successful which shows the potential for PM-gears.
We have compared part price for PM-gears and forged gears and in many cases there is an obvious favour for PM-gears.

3. Objective

The goal with this project is to increase the participants knowledge about design, manufacturing, material properties and costs for PM-gears but also to increase the knowledge among the end line users

There is a long experience and standards guiding how to design conventional machined steel gears. There are also S/N-curves for different materials available.

For PM-gears there is a very limited knowledge available but to commercialize PM-gears the same information as for steel gears must be available.

As there is a very tough cost focus in the automotive industry a main objective for new materials and manufacturing techniques is reduced product cost and reduced investments.

This project will compare product cost for PM-gears with conventional produced steel gears.

4. Project realization

At start of the project some end users were visited to check there interest and inform about the status of PM-technology for gear manufacturing

We have continuously informed about the new results in the project for example at the yearly FFI conference in Katrineholm and also at visits to domestic and international end users.

PM-gears compared to conventional machined gears from forging

We have studied the possibility to replace conventional machined gears from forging for use in automotive and truck applications as engines and gearboxes.

The study showed that from strength point of view about half of the number of gears could be replaced by PM-gears without any strength increasing treatment as for example rolling or Hot Isostatic Pressing (HIPing).

Reengineering of a gearbox

Vicura has redesigned both a gearbox for electrical cars from conventional steel gears to PM-gears and also an Opel-gearbox (M32) which is used in the last model of SAAB 9-5. The weight of the gearbox was reduced by 1,1 kg by using PM-gears.

Prototypes for the electrical car gearbox have been manufactured and manufacturing of the gears for the M32 gearbox is going on. It is planned to have the PM gear box running in car at summer 2013.

The most loaded gears for gear ratio 1 and 2 will have convoloid and asymmetric teeth to compensate for less strength for PM-gears. It is possible to optimize the geometry of the gear root with PM-technology to improve breakage resistance compared to hobbed gears. By hobbing the method there is limited possibility to change the root geometry.

Calculations show that it is possible to gain 8-15% by optimized design of the gear root.

Practical experiments with PM-gears

To show that PM-gears will work in automotive gear boxes the gears for ratio 3, 4, 5 and reverse gears in a SMART-car was replaced with PM-gears, Fig 1. This car has so far been running for 120’000 km without any problems with the gear box. The test will continue to 200’000 km before the gear box will be disassembled.

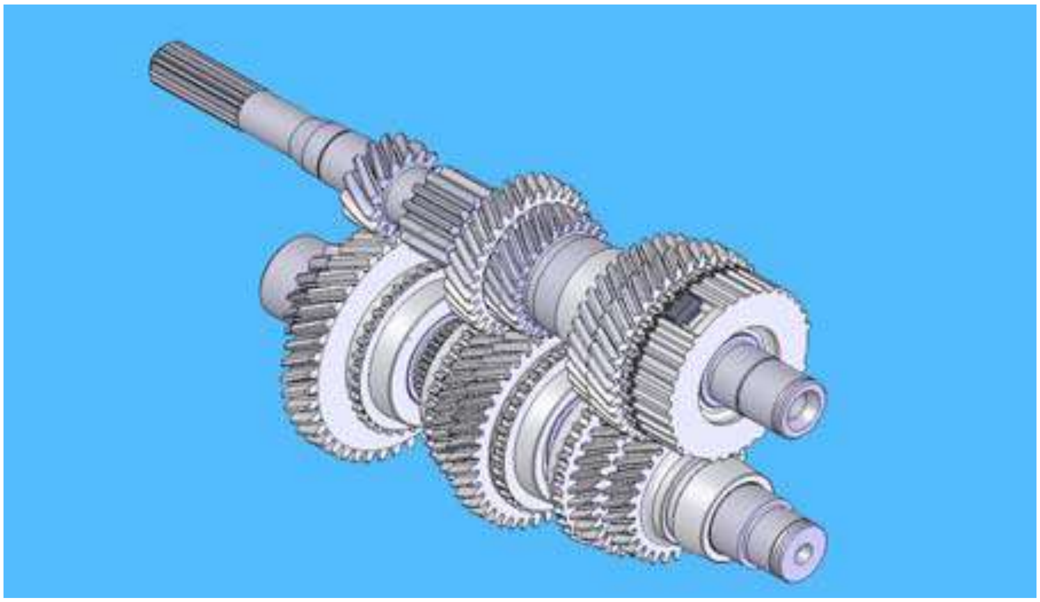

Fig 1. Layout of gear box for a SMART-car.

Due to less weight and less inertia the fuel consumption is calculated to be reduced by 6% at acceleration compared to the original steel gears. PM has less density compared to steel and does also show new design possibilities which maybe are not possible to machine or too expensive to machine which can contribute to reduced weight.
It is also positive that less inertia decrease the load on synchronization parts and faster gear shifting.
To show that PM-gears can be used also in high loaded application the gears and clutch part for a Mitsubishi EVO9rally car, Fig 2, was replaced by Hipped PM-gears.
The car has been used for 3 seasons with no problems. At disassembly the gear teeth showed no unnormal signs of wear or damage. The wear of the dog clutch teeth was less for the PM-parts compared to the steel parts as can be seen in fig 3 and 4 after 550 km rallying.
The coupling parts shown in fig 3 and 4 are mating parts.
It is worth to notice that the teeth width of the PM-clutch part is only 10 mm compared to the steel teeth which is 15 mm. The chipping seen at the corner of the PM-clutch teeth had probably been avoided if the PM-part teeth also had been 15 mm wide.

Fig 2. Mitsubishi EVO9 with PM-gears in the gearbox.

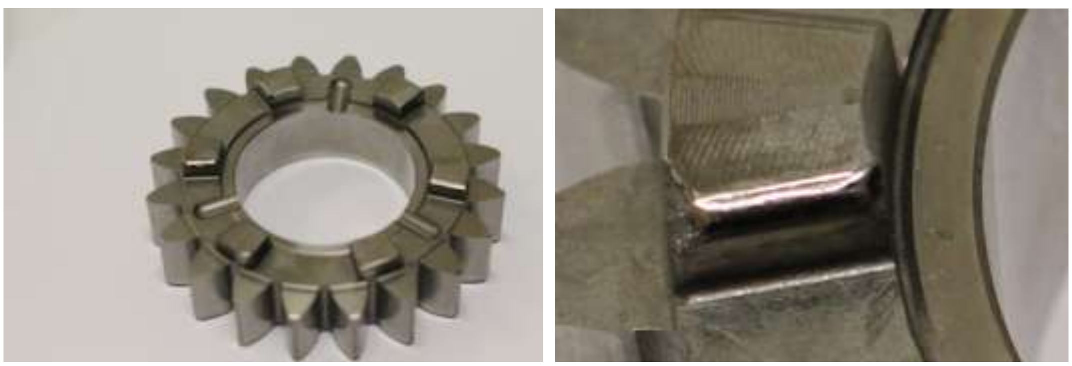

Fig 3. Gears in case hardened A85Mo5.

Fig 4. Clutch part in case hardened steel.

Material properties

To produce material data i.e. S/N-curves, a FZG-test machine from Strama is bought, Fig 5.
Vicura have designed the FZG-gears for the test machine and also for pulsating test for testing the root bending fatigue.
Available and reliable material data is absolutely necessary for design of PM-gears.
Figure 6 shows result from ongoing FZG-test.
The FZG-test rig will also be used in another project sponsored by “Energimyndigheten” where PM and steel gears are compared regarding efficiency, wear and running in behavior for different finish machining methods and different lubricants.

Fig 5. FZG-testrig for production of S/N-curves.

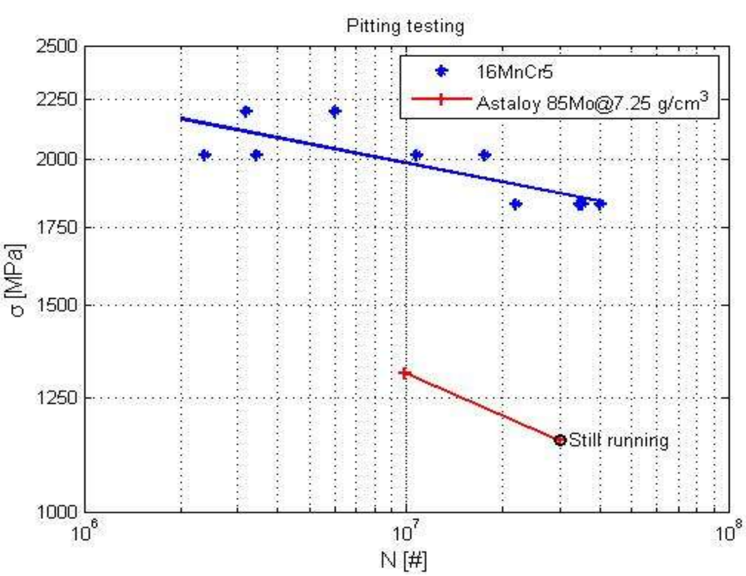

Fig 6. Results from ongoing production of S/N-curves for steel 16MnCr5 and PM-quality A85Mo.

As PM is fully isotropic it is reasonable to believe that PM-gears will be less distorted at case hardening compared to steel which is less isotropic. We have compared heat distortion at case hardening for 10 thin rimmed ring gears made of steel, shown in Fig 7, with 10 PM-gears made of A85Mo.

GEAR DATA		
Number of teeth	z	118
Normal Module	m_n	1,5
Gear width	B	15
Pressure angle	a	15º
Helix angle	b	15º
Direction of Helix		
Helix at base circle	b_B	
Normal profile shift coefficient	x	
Reference diameter	d	183,24
Base diameter	d_B	
Tip diameter	da	186,25 h10
Root diameter	df	179,5
Span width/ over K teeth	W/k	66,95/15
Measurement over balls	M_d	186,57
Ball diameter	d_M	2,5
Involute start diameter	SCP	

Fig 7. Geometry of ring gear for comparison of heat distortion at case hardening.

The result is summarized in table 1. Maximum unroundness is less than half for PM-gears compared to steel gears and the variation in diameter change is also considerably less. The test was done in a conventional pusher oven. With more adequate fixtures and low pressure carburizing and gas quenching the distortions would most likely become even less.

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	PM		Steel	
	Diameter change	Change in Roundness	Diameter change	Change in Roundness
Average 10 parts	0,04069	0,0717	-0,21106	0,12558
Max	0,0553	0,1228	-0,1856	0,2236
Min	0,0169	0,0151	-0,2909	0,0533
Variation	0,0384	0,1077	0,1053	0,1703

Table 1. Distortion of ring gear at case hardening .

We see a good potential for PM-gears especially in electrical and hybrid vehicles where thin rimmed gears are commonly used when considering increasing demands on lower noise. The quality for the finish machined gear is very dependent of the quality before finish machining. If large geometrical errors need to be corrected gear grinding is the only method which is extremely costly. Our tests indicate that the distortions for ring gears at case hardening can be limited to values that are possible to correct with gear rolling or gear honing which is costly realistic.
Tests indicate that PM has better damping compared to steel gears which is also especially favorable in electrical vehicles.
Försök tyder också på att PM dämpar ljud bättre än stål vilket också är positivt, speciellt för elbilar.

Production cost and economy

Part cost calculations have been made for a number of gears considering that the gear is compacted to the final geometry. Sintering and case hardening is performed in a low pressure carburizing and gas quenching process.
Finish machining is done in conventional way, turning or grinding of bores and faces.
The gear quality reached by gear grinding or gear honing. A typical example is shown in Fig 8.

Figure 8. Conventional machined gear from forged steel.

Process flow conventional production:

Forged blank – Turning – Hobbing – Broaching of key way – Case hardening –

Hard turning of bore – Gear grinding

Process flow for PM-gear:

Compacted blank – Sintering and case hardening – Hard turning of bore – Gear grinding

In some cases an additional machining in soft may be necessary.
The material waste for sintered gears is only a few percentage compared to typically 30% for conventional machined gears from forging.
For the gears we have studied the part price for PM-gears will be in the range from 10 to 30% lower.
The investment cost will also be much lower due to very high productivity in the compaction process and the geometry is set in one operation compared to many operations for machining. The foot print will also be considerably less.
The common opinion is that compaction tools are expensive and can only be carried by very high volume of parts.
The truth is that tooling cost for PM-gears is not that much higher compared tooling cost for conventional machining. Depending on how complex the gear geometry is PM-gears can be competitive at annual volumes of 10’000.
PM shows new possibilities to design for weight reduction or fool proof assembly which are impossible or too costly to machine, Figure 9. Parts that need to be machined separately can sometimes be compacted as one part or brazed together in the sintering process.

Fig 9. Weight optimization of PM-gear

Machinability

SwePart have machined both different qualities of PM and steel FZG-gears designed by Vicura.
The steel gears are conventionally machined from pucks made of 16MnCr5 and the PM-gears are made from pucks in A85Mo and Hipaloy.
For both PM and steel inserts from Seco was used by turning. The cutting data was moderate, speed 240 m/min and feed rate 0,3 mm/rev. Cutting depth 3 mm.
insert
The machinability of A85Mo was comparable to turning of nodular cast iron.
For turning of Hipaloy insert WNMG080408 with chip breaker MF3 seemed to work best. The machinability was more like turning stainless steel.
Also for Hipaloy the inserts needed to be replaced every 8th minute. The chips were short.
Only A85Mo was hobbed with a conventional PM-hob material ASP 2030 coated with Alcrona. The number of parts hobbed was not enough to show any difference in wear between steel and PM.

However, the tip of the cutting teeth maybe showed slight indication of being more heated at hobbing PM-gears compared to hobbing steel gears.
We will very clearly point out that no efforts were paid to find the best insert or cutting data. It is positive that no problems with chip breaking existed.'
Maybe different powder mixes can be favorable for machining.

At hard finishing, turning and grinding, no difference was noticed in machinability between PM and steel.

5. Results and deliverables

5.1 Delivery to FFI-goals

- The material need at PM-make is up to 30% less compared to conventional gear making from forged blank. Consequently the energy consumption will also be reduced also because of reduced need for machining. In general the energy consumption to make PM gears is 30% less compared to conventional gear production. Case hardening which consumed much energy can for PM gears be made in the sintering process which also saves energy. Considering less density for PM compared to steel and possibilities for weight savings in design a reduction of energy consumption for the vehicle at acceleration can be estimated to 8-22%.
- Considering that Höganäs AB is number one in the world regarding production and knowledge of metal powder for high performance applications as gears it offers good potential for Swedish industry to be leading in gear making with PM.
  The business potential is enormous in the future especially as the number of gears seems to increase with hybrid and electrical vehicles.
- Replacing conventional machined gears and case hardened gears from forged steel with PM-gears means reduced part cost, less weight, less energy consumption at production and for the vehicle. PM also offers new design possibilities.
- This project has contributed to building more competence and research.

1. A Ph.D student is employed at KTH to work with tribological properties for PM-gears.

2. One MSc engineer is employed at Swepart to increase the knowledge of PM gear making and design.

3. A follow up project sponsored by ”Energimyndigheten” is started up where also LTH and Borg Warner is participating to study efficiency and wear of gears depending of material, method of finish machining and lubricant.

6. Dissemination and publications

6.1 Knowledge and results dissemination

The result from this project has continuously been reported at the yearly cluster conference in Katrineholm and at regularly meetings at the Swedish Transmission cluster. Swedish and international end users have been informed at meeting.

7. Conclusions and future research

In this project we have shown that it is possible to replace conventional gears with PM-gears also in high loaded applications as gearboxes for cars and gears in diesel truck engines.
The PM-technology offers a number of advantages as:

- Reduced cost for the component
- Less distortion at case hardening and machining
- Less energy consumption at production
- Less material needed for producing the part
- Less investment cost and buildings
- Reduced weight for the vehicle
- Reduce fuel consumption for the vehicle
- New design possibilities
- Reduce noise

To allow increased use of PM-gears material data and design rules must be available. For steel gears experience and standards are available for the designer.

8. Participating parties and contact person

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