TEKA Kom. Mot. i Energ. Roln. – OL PAN, 2011, 11c, 53–63

REDUCING ENERGY CONSUMPTION DURING MANUFACTURE OF SEMI-FINISHED COMPONENTS OF THE PLANETARY GEAR THROUGH THE USE OF CASTINGS MADE BY RAPID PROTOTYPING

Andrzej Gil*, Piotr Kowalski*, Krzysztof Wańczyk*

[a] Laboratory of Rapid Prototyping Techniques, Centre for Design and Prototyping,
Foundry Research Institute ul. Zakopiańska 73, 31-418 Kraków, Poland

Summary. This paper proposes a reduction of energy consumption in the implementation of semi-finished components of the planetary gear through the use of foundry technology. The authors compared the calculated amount of sliced material for individual pieces made in technology to bring the full semi-solid and prototype castings. Next presents the selection of materials, development of casting technology parts analyzed, and the various stages of their execution. The final result was semifinished, which, after final machining are to be submitted for testing supplies.

Key words: Casting, planetary gears, rapid prototyping, machining.

INTRODUCTION

The transmission components of machines and vehicles are usually made from various types of metal alloys using two different manufacturing techniques. The first technique is machining, where the required shape of the semi-finished product is obtained by removal of material from a solid workpiece. The second method is casting of components, which are next subjected to a finishing treatment. Naturally, each of these methods has its own advantages and drawbacks, but the choice of a more economical one depends on factors that characterise the currently produced component. A good example of the casting process used as an alternative solution to the fabrication of elements from solid blocks of materials are parts of the planetary gear used in motor vehicles designed for operation under heavy loads [2, 5, 9].

Typically, the primary planetary mechanism is composed of the three types of gears, meshed all the time. The wheel with external teeth, called sun wheel, is located in a central part of the transmission system. Around the sun wheel are arranged the intermediate wheels, or planets, whose axes of rotation are embedded in the yoke (or basket), and there are usually between two and five of them operating in the system. Planets are meshed with an outer gear with internal teeth, placed axially in relation to the sun gear. The planetary mechanism starts operating as a transmission gear allowing the transfer of torque as soon as one of the above mentioned elements is locked, thus enabling movement of the other two elements, giving the required ratio resulting from the diameter of the individual gears. As a consequence, the three basic modes of operation are obtained:

- sun wheel locked – planets and the outer ring wheel rotate,
- planets yoke locked – the sun wheel and the outer ring wheel rotate,
- outer wheel ring locked – the sun wheel and planets rotate.

The advantage of a gear of this type is its compact design, which allows obtaining much higher ratios than the ratios obtainable in a standard gear, and also different ratios in different modes of operation.

Among the numerous applications of planetary gears, one of the possibilities is to use them as structural components of the drive system of motor vehicles. One of the solutions is to place the planetary gear inside the wheel hub, which enables using the gear mechanism to reduce the torque on the shaft. At the same time, by getting higher torque, the wheel decreases its rotational speed. In practical applications, the design of this mechanism is much more complex than the model example described here and consists of numerous mate parts.

PURPOSIL AND METHODS

For designs of this type, three components of the mechanism were selected as parts that can be successfully made by casting. These parts are: gear body, ring wheel and cover. Until now, these components have been manufactured by subsequent operations of boring and turning from solid cylinder. Machining allows making items of good quality, free from any hidden material-related defects, but an evident drawback of the technology is the large volume of waste in the form of chips produced from the machined workpiece, as well as a high wear and tear of the cutting knives and lathe tools. The large quantity of the removed material is directly related to the overall dimensions of the machined elements; of some significance is also the fact that in the case of the ring and body, making the cylindrical shape also requires the removal of material from the cylinder interior.

Using casting technology as an alternative enables making these elements as semi-finished products, which after removal of a relatively small machining allowance will give the same shape as in the case of turning and boring from the solid body [1, 2].

To compare the volume of material removed in both processes, as a reference product, the components at a comparable stage of machining were used. The shape reflected the external and internal outlines of the finished product, but the blanks had no holes and final finishing which are usually done in subsequent operations. This allowed determining the difference in the volume of material removed at the first stage of machining, the outcome of which is obtaining the base product shape. At the same time it was be assumed that the differences in energy consumption by the compared technologies should be analysed for and until this stage. To calculate the weight of the cylinders used as a starting stock for the machined components, their minimum dimensions were adopted, where outer diameter and height of the blanks were equal to the diameter and height of the ready components. In the case of castings, the weight of the raw components with machining allowances and drafts but without the gating and feeding systems was adopted.

The need for feeding the castings is a natural consequence of the cast metal contraction when it passes from the liquid to solid state; the additional problem in this case is the formation of hot spots in castings. The casting sole-to-casting with gating and feeding system ratio gives percent yield and determines the liquid alloy volume that should be ready to make one cast component. The gating and feeding systems separated from the casting make a good quality scrap used as a charge in the subsequent melting operations.[17-20]

Recycling of chips produced in the machining process is both complicated and energy consuming. Chips to be melted require deoiling and briquetting.

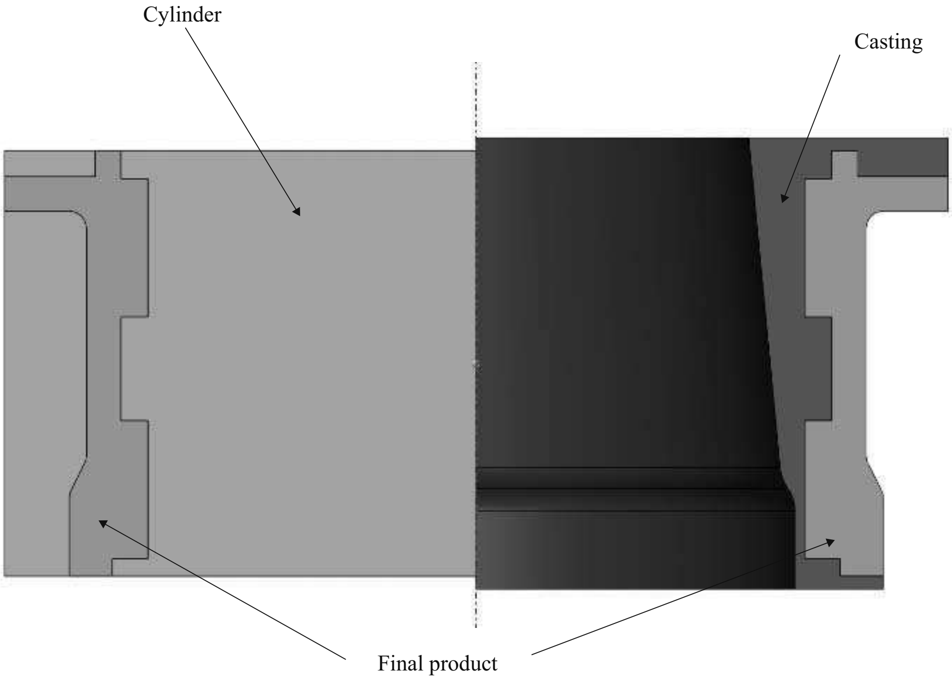


Fig.1. Comparing the waste material volume removed by machining and casting

Table 1. The weight of material consumed by comparable manufacturing technologies to make one set of the semi-finished products

Element bored and turned	Estimated material consumption calculated in kg						
	Ring wheel		Body		Cover		Total waste in the form of chips
	5,988		11,126		1,507		
	Starting material	Chips	Starting material	Chips	Starting material	Chips	
Cylinder	28,941	22,953	53,586	42,460	6,464	4,957	**70,370**
Casting	10,941	4,953	14,724	3,598	1,724	0,217	**8,768**

The calculation of energy consumed by the casting process is a very complex problem because of a large number of the different factors that take part in this process. It leaves no doubt that most of the energy is consumed by the melting process, but it is important to note that, besides the melted metal type and the furnace type and capacity, some impact on the energy consumption has also the technical condition of the melting installation. Another issue is the process of foundry mould preparation, which can differ in terms of both technology and energy. Practically every foundry operates a technological line of its own design, and the efficiency and performance of devices can vary widely among each other. The additional factor influencing the solution adopted in the technical design of a moulding process is the size of the manufactured batch of castings. It is difficult to imagine that energy consumption might be the same for making a few pieces of the cast items only and a large batch of products, the more that the additional factor of the tooling cost and machine redesigning is also involved here.[2-7,14,16-18]

At the Foundry Research Institute in Cracow, studies have been conducted on the possibility of making several prototype cast semi-finished elements of the planetary gear for further performance tests. To achieve this goal, the method of rapid prototyping was used.[5,9,10,15]

Parts of the transmission gear were cast by the sand mould technology, which can be divided into the following stages:

1) designing of 3D foundry technology (allowances, the gating and feeding systems),
2) making virtual patterns and technical documentation for foundry tooling,
3) making foundry patterns (pattern plate or common foundry patterns),
4) making moulds from foundry patterns,
5) melting of selected cast alloy,
6) pouring of moulds,
7) cooling of castings and knocking out from foundry moulds,
8) fettling of castings, degating and removal of feeders.

RESULTS AND DISCUSSIONS

The basis for the development of casting technology is the cast part shape, i.e. the overall dimensions and the degree of intricacy; of some importance is also the cast material type. First, based on the supplied documentation, 3D computer models of individual cast pieces were made, allowing for the necessary technological allowances and drafts. Because of the effect of linear contraction, patterns were enlarged by the values of this contraction, which is 1% and 2% for the cast iron and steel, respectively. Then, the gating and feeding systems were selected in sizes that guarantee making sound castings. Thus prepared documentation was used in the development of moulding technology, including various foundry patterns, core boxes and a configuration of feeding systems. Studies also included joining of individual tooling parts with alignment pins, the use of which ensures the correct assembly of foundry equipment [4, 9].

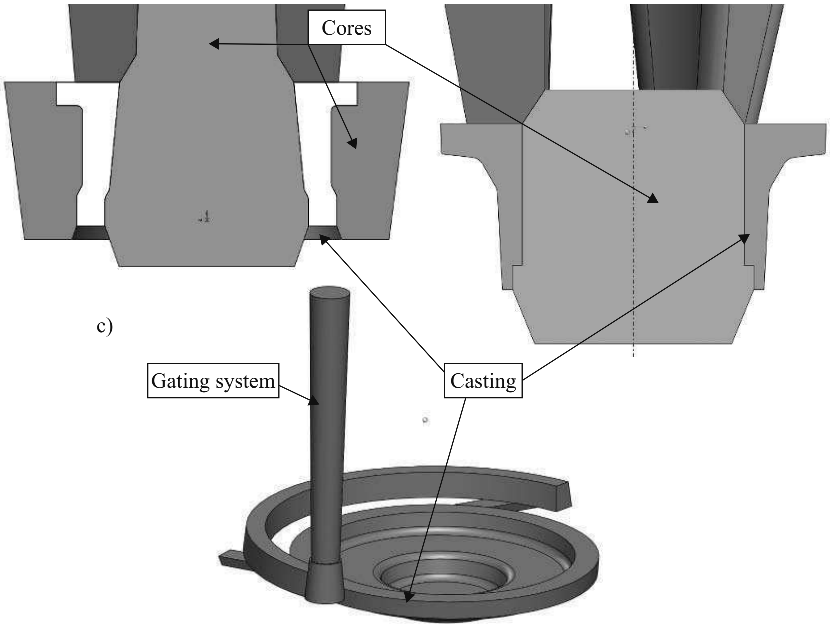
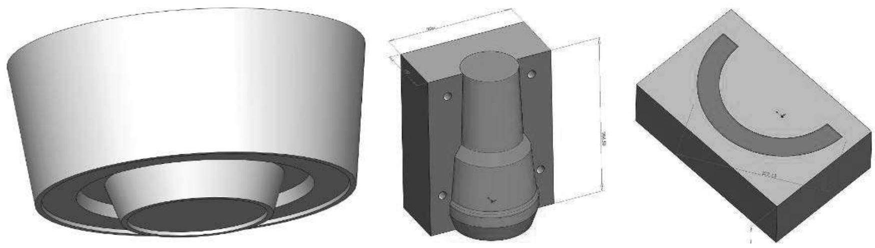
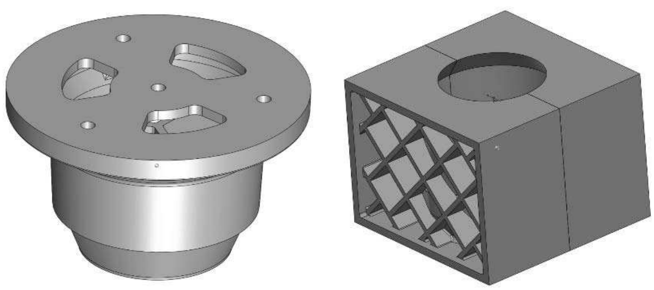


Fig. 2. Casting technology to make successive elements
of the transmission gear: a) ring wheel, b) body, c) cover

a)



b)



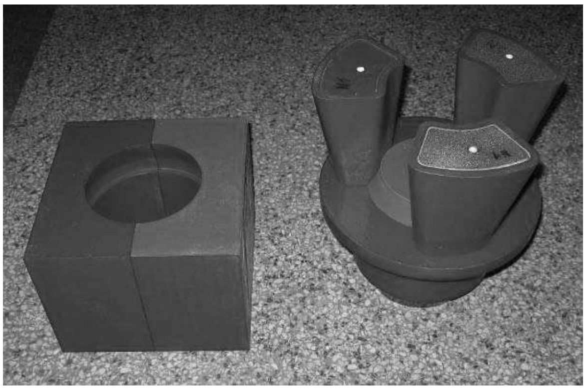
c)

Fig. 3. Pattern tooling to make individual parts of the transmission gear: a) ring wheel, b) body, c) cover

Foundry patterns were made by the 3D Printing technology, i.e. three-dimensional printing on the layers of powder. The use of the technique of rapid prototyping allows making a real pattern directly from the 3D files of the prepared documentation. To minimise the volume of material used by the 3D printer, models were printed in the form of shells, and to increase their strength, a ribbed internal structure was designed. Patterns obtained by this technique were hardened soaking them with epoxy resin. Empty spaces inside patterns were filled with special fillers, and holders were attached to patterns to facilitate lifting them up from the ready mould. The last step was coating of patterns with a layer of protective paint [11].

a)

b)



c)

Fig. 4. Foundry patterns: a) ring wheel, b) body, c) cover,

As a material for moulds and cores to reproduce the casting of a cover, the self-hardening moulding mixtures based on silica sand with furan resin as a binder were used. In the case of bodies and rings, they were cast in common bentonite-bonded sand mixtures; cores were made in furan resin sand.

Moulds for casting of the cover were made as two halves, i.e. cope and drag, one half mould for casting one cover. The drag was made by placing patterns on the bottom plate with a frame, which was filled with moulding sand, compacted at the next step of operations. Then the whole was turned over, and after removal of the bottom plate, cope was moulded in the same way. After pulling the patterns out and adjustment of the gating system, the half moulds were assembled together and joined with a moulding glue. The glue was used to prevent molten metal from flowing out from the mould along the parting plane during pouring. The cast material was grey iron GJL200.

Fig. 5. Foundry moulds of cover

In moulds for casting of bodies and rings, inner cores had to be used. In the case of rings, moulds were additionally provided with pulled out outer parts. The casting shape was reproduced in core boxes filled with furan sand mixture. Mould cavities were reproduced by patterns with core prints. Moulds for bodies and rings were made from bentonite sand. In the upper part of mould, risers were placed, and their shape was reproduced with patterns joined to the pattern of the casting by means of centring pins. Risers were used to move the hot spots outside the casting area and feed them with liquid alloy during solidification.

To assemble moulds and make them ready for pouring, cores were first placed in the bottom part of mould and the mould was next closed with its upper counterpart and loaded. The bodies were cast from the GS-25CrMo4 steel (DIN 17205), while rings were cast from the L40HM steel (PN-88/H83160).

For casted components of the planetary gear, the alloys of metals have been melted in a medium-frequency induction furnace. Three different cast materials were melted, each of them being adjusted to the respective type of castings. The individual cast alloys and the respective pouring temperatures are compared in Table 2. [22,23]

Table 2. Alloy grades and pouring temperatures selected for individual castings

Casting	Material	Standard	Pouring temperature ˚C
Cover	Cast iron - GJL200	-	1380
Body	Cast steel - GS-25CrMo4	(DIN 17205)	1570
Ring	Cast steel - L40HM	(PN-88/H83160)	1550

After pouring and cooling, castings were knocked out from moulds and cleaned. Then the gating and feeding systems were cut off. Castings were evaluated for the presence of possible casting defects and checked for the dimensional accuracy. The results of the check have proved that castings are characterised by good surface quality, and are free from any serious defects, while their dimensions are consistent with expectations. Thus prepared cast parts of the planetary gear were handled for further machining.

Fig. 6. Semi-finished castings of the planetary gear

CONCLUSIONS

The technology of casting semi-finished components of the planetary gear is regarded as a highly competitive process with the technology of machining these elements from a solid block of material. Comparing the volume of material removed during machining and casting (Table 1), it clearly follows that casting generates less chips and shortens the time of this operation. The difference in the amount of the machined material exceeds 60 kg for one set of gears; this value becomes particularly important in mass production of these elements, where it goes into tons.

The energy consumption by the manufacturing process should also be considered in terms of the possible recycling of the waste material. In the case of casting, a large part of the material allowance is process scrap in the form of gating and feeding systems, which can be easily reused within the same plant, while the same cannot be easily said of the chips formed during machining.

Last but not least, the reduced energy consumption is reflected in the price of the final product; lower production costs with high quality maintained raise the competitiveness of the company in the market. Today, the modern metalcasting industry pays more and more attention to the problem of energy consumption in the manufacturing processes, believing that its continuous reduction will bring even better economic results in future.

REFERENCES

1. BUBICZ M.: *Raport: Szybkie prototypowanie cz. I – przegląd dostępnych rozwiązań. Maszyny, materiały, zastosowania*. / Projektowanie i Konstrukcje Inżynierskie 6(09) czerwiec, 2008, p. 14 - 21.
2. CHUA C.K., LEONG K.F., LIM C.S.: *Rapid Prototyping. Principles and Applications,* World Scientific, Singapoore 2004.
3. PŁATEK P., Kret M.: *Techniki druku 3D – przykłady zastosowań metody FDM, warstwowego osadzania topionego materiału*. Seminarium techniki szybkiego prototypowania w cyklu życia produktu. „Mechanik" 2008, nr12.
4. DYBAŁA B.: *Technologie szybkiego prototypowania i wytwarzania*, W: „Raport. Rapid Prototyping & Reverse Engineering", 2010.
5. SOBAŚ A.: *Od idei do produktu czyli rapid prototyping*, Warsztat, 2010.

6. BUBICZ M.: *Cyfrowe czy jednak fizyczne? Prototypowanie – wyzwanie XXI wieku*, Konstrukcje inżynierskie 2007, nr 1.
7. CHOJNOWSKA L.: *Model wirtualny wsparty wydrukiem 3D*. Desing News w Mechanice i Elektronice, 2008, nr 03.
8. CHUCHRO M., CZEKAJ J. RUSZAJ A.: *Wytwarzanie modeli funkcjonalnych i narzędzi metodą selektywnego spiekania laserowego (SLS, DMLS)*, Mechanik nr 12/2008, str. 1064
9. GUSTAFSON R.: *Rapid Prototyping: a tool for casting design and verification*, Mod.Casting 1999 Vol.89 nr 3 s.44-47.
10. HUMML W., HAEMERLE H.: *Metallische Prototypen in hoher Qualitaet durch innovative Feingiesstechniken*, Konstruieren+Giessen 2005 Jg.30 nr 1 s.10-13, bibliogr.1 poz.
11. KROKOSZ J., MŁODNICKI S., GIL A., KARWIŃSKI A., PABIŚ R., ĆWIKLAK R.: *Ocena możliwości wykorzystania technik szybkiego prototypowania w odlewnictwie oraz opracowanie założeń i wykonanie serii modeli i odlewów artystycznych*, Odlewnictwo współczesne – Polska i świat 2010, nr 1, str.3-13.
12. LEWANDOWSKI J.L.: *Postęp w zakresie szybkiego prototypowania*, Przegląd Odlewnictwa 3/2001 str. 116-117.
13. OCZOŚ K.E., *Rapid Prototyping - znaczenie, charakterystyka metod i możliwości*, Mechanik 1997, 70 nr 10 s.441 – 452.
14. PĄCZEK Z., KARWIŃSKI A., KROKOSZ J., PRZYBYLSKI J., PYSZ S.: *Zastosowanie technik LOM do wykonywania odlewów, możliwości, szanse, problemy*, wyd. Instytut Odlewnictwa – Kraków, Kraków, 2003.
15. WUENSCHE R.:*Rapid Prototyping bei der Herstellung von Gussteilen*, Giesserei 2004 Jg.91 H.4 s.44-46.
16. CHLEBUS E.: *Innowacyjne technologie Rapid Prototyping – Rapid Tooling w rozwoju produktu*. Oficyna Wydawnicza Politechniki Wrocławskiej. Wrocław 2003, s.37-42,47-57,106-140,152-158.
17. RUSZAJ A.: *Niekonwencjonalne metody wytwarzania elementów maszyn i narzędzi*. Wydawca IOS w Krakowie. Kraków 1999,s.288,299.
18. OCZOŚ K.E.: *Rosnące znaczenie Rapid Manufacturing w przyrostowym kształtowaniu wyrobów*. Mechanik (2008)4, 256.
19. OCZOŚ K.E.: *Zastosowanie techniki Rapid Tooling do kontroli jakości wytwarzanych części samochodowych*. Mechanik (2008)12, 1022-1028.
20. OCZOŚ *K.E.: Rozwój kształtowania przyrostowego wyrobów*. Mechanik (2007)2,65
21. PLICHTA J., PLICHTA S.: *Techniki komputerowe w inżynierii produkcji*. Wydawnictwo Uczelniane Politechniki Koszalińskiej, Koszalin 2006.
22. Pirowski Z.,Gościański M.: *Consturcion and technology of production of casted shares for rotating and field ploughts* Teka komisji motoryzacji i energetyki rolnictwa, PAN O/Lublin, T. IX, s. 231-239.
23. Pysz S., Karwiński A., Czekaj E.: *An analysis and comparision of properties of Al-Si alloyautomotive castings made by rapid prototyping and standard lot producton.* Teka komisji motoryzacji i energetyki rolnictwa, PAN O/Lublin, T. IX, s. 251-258.

ZMNIEJSZENIE ENERGOCHŁONNOŚCI WYKONANIA PÓŁFABRYKATÓW ELEMENTÓW PRZEKŁADNI PLANETARNEJ POPRZEZ ZASTOSOWANIE ODLEWÓW OTRZYMANYCH Z WYKORZYSTANIEM METOD SZYBKIEGO PROTOTYPOWANIA

Streszczenie. W artykule przedstawiono propozycję obniżenia energochłonności wykonania półfabrykatów elementów przekładni planetarnej poprzez zastosowania technologii odlewniczej. Porównano obliczone ilości skrawanego materiału dla poszczególnych detali wykonywanych w technologii wytaczania z pełnej bryły oraz z półfabrykatów odlewów prototypowych. W dalszej części przedstawiono dobór materiałów, opracowanie technologii odlewania analizowanych detali oraz poszczególne etapy ich wykonania. Efektem końcowym były półfabrykaty, które po ostatecznej obróbce skrawaniem mają być przekazane do testów eksploatacyjnych.

Słowa kluczowe: Odlewanie, przekładnia planetarna, szybkie prototypowanie, obróbka skrawaniem.