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DFM(A)-ASPECTS OF AN ADVANCED CABLE GLAND DESIGN

Keywords: DFMA, Turning, Grounding, Electrical drives

ABSTRACT

Nowadays typical motor junction boxes do not incorporate cable glands, which would provide good electrical performance in terms of electromagnetic compatibility. In this paper, a manufacturability and assembly analysis for the new construction of a rigid body feeder cable junction of an electric motor is presented especially for converter drives (practical tests were carried out at LUT during 2007). Although the cable junction should also clamp the cable to provide enough tensile strength, the phase conductors should not get squashed by the grounding connection. In order to ensure good performance in an electrical mean especially in converter drives, the grounding of the cable should be connected 360 degrees around the cable. In this paper, following manufacturing technologies are discussed: traditional turning, precision and centrifugal casting, and rotation moulding. DFM(A)-aspects are presented in detail.

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1 Introduction

The number of frequency converter drives is at a constant increase in the industry and it is predicted that this trend will continue at an increasing rate especially in low voltage drives. This development is driven by the desire to for example improve energy efficiency, which can be achieved by the use of a frequency converter. However, converter drives require special considerations in terms of cabling and grounding, which renders the solutions found in traditional straight-to-grid connected drives insufficient.

In this paper, a manufacturability and assembly analysis for a rigid body feeder cable junction of an electric motor is carried out especially in terms of converter drives. The motor junction box is used to provide necessary connection terminals for the motor feeder cable and also to ensure grounding of the installation, which is important for electrical safety.

Typically, the junction box is not designed for easy assembly and the making of connections is usually quite an awkward task. The process of connecting the feeder cable to the motor junction box typically requires many stages, different tools, and has to be made from numerous assembling directions. Also, the junction box is designed for straight-to-grid connected motors and therefore the grounding connection is provided in terms of electrical safety and not very much attention has been paid to ensure proper and easy grounding connections. The grounding connection is typically carried out by stripping a long piece of conductor and connecting it to a grounding terminal. This type of grounding has inadequate high frequency electrical performance in frequency converter drives.

Especially in modern frequency converter driven drives, the selection of the interconnecting feeder cable and proper groundings in the installation are important, see [1], [2]. In this type electrical drives, the drive itself produces electromagnetic interference (EMI) as a product of operation. To minimize the effects of EMI, the grounding must be properly installed. Also, due to the high frequency content of the voltage waveform and common mode voltages, the grounding must also be eligible on radio frequencies. In addition, to provide electrical safety, the grounding must be electrically strong.

The cable gland design is focused on these requirements. In order to obtain the guidelines for easy manufacturing and assembly, a specialized DFM(A)-questionnaire is generated for the cable gland design. The cable gland contains only standard threads and no specialised tools are needed in assembling, only the cable needs to be stripped. The prototype can be manufactured by turning, and in serial production the gland can be manufactured by precision casting. Also, the new gland concept has been presented at the International Manufacturing Conference, see [3]. Presented aspects and results of DFM(A)-analysis, which are presented in this paper are based on the practical tests carried out at LUT during 2007.

2 Basic principles of DFMA

The term DFMA emphasizes the fact that designer has to be responsible for taking into account the manufacturability aspects during the design process and not afterwards during redesign stages due to feedback coming from manufacturer. The term DFMA also points out that the design of the product can be regarded as the ”first manufacturing stage” of the product. And finally the term DFMA tries to emphasize that designer must ensure that his ideas are both functional and reasonable and feasible to manufacture.

The main goals of DFM/DFMA are:

- to improve the integration between design and manufacturing
- to reduce product developing time and cost
- to improve product quality and reliability
- to shorten lead time
- to increase productivity and
- to answer faster to customers requirements

The basic operations to carry out DFMA are as follows:

- minimize the number of parts in a construction
- design modular constructions
- try to find as many functions for a part as possible
- avoid additional components for joining other parts
- design the construction so that all the parts can be assembled from the same direction
- minimize the number of different manufacturing methods and stages to be used
- obey the rules of easy manufacturing for each manufacturing method (applied into your own production)
- check that there is enough space for necessary tools during assembly, fixing systems during manufacturing and a robotic gripper in automated systems
- use standardized geometry, tools and components
- check the machining allowances
- check the suitability of the material for the manufacturing methods
- use appropriate general tolerances for your own production
- check the summarized errors of the assembly and design a harmless place for manufacturing errors in the construction
- check that the values of surface roughness, tolerances for linear and angular dimensions and geometrical tolerances are adjusted together
- use parts, which can be assembled from several directions and still function perfectly (avoid parts, which can easily be assembled in a wrong position or which function only in one position)
- if there are several possible manufacturing methods choose the one, which needs least preparations
- try to repeat the same manufacturing stages, think that each manufacturing stage is also ”a module”
- use parametric design
- design the products directly for automated production (in most cases they will be extremely well suitable for manual production too)
- if manual production is used check the ergonomic aspects

2.1 Some tips for effective use of computer aided means for DFMA

It is necessary in practical work to avoid the modelling of the same geometry several times during the process. This means that it must be possible to fully integrate all the software packages used in the process. That is why modular software applications are favoured in which sketching, drafting, design, finite element analysis (FEA), and simulation of manufacturing process are linked together.

All the data produced during the process should be saved in a local database, which forms the basis for further development of more general databases, expert systems and artificial intelligence systems. On the other hand, by combining the data from databases the designer can formulate standard-based or/and modular constructions starting from the sketch in the very early stages of the design process. These databases should be compatible with the ones of all the suppliers' and customers'.

The use of standardized and modular constructions forms the important starting point also for computer aided design. It is easy to add feature-based information into the data of standard components, parts, sub-assemblies or the entire construction, to be used for the design of manufacturing or process planning.

Different kinds of simulations and visualizations are used to illustrate the propagation of the design process. By using virtual models it is possible to combine geometrical, physical, functional and manufacturability simulations of the product. However, if the simulations or virtual models are used only for replacing the conventional drawbacks due to a contradiction between the designer and manufacturer very little advantage will be achieved with ”computer aided drawback”. In this case it is namely annoying that more time will be wasted for modelling than would have been spent with useful conversations with the manufacturing plant.

To make the early steps of the design more effective either parametrical modelling or rule based design systems can be used. Of course the appropriate use of blocks (either made by the designer himself or possibly ready-to-use blocks) and layers will improve the efficiency of the actual work with the computer.

Both local and global network solutions are needed. Nowadays Internet applications have become common in different areas. The basic problem in the use of networking for engineering design is the question of data transfer security.

The most effective way to shorten the time needed to complete the product documents for manufacturing is the use of feature based systems. Either:

- form features (for example not just the sphere but a sphere of a ball bearing),
- geometric features (for example not just the dimensions of a bored hole but also the direction of this cylinder) or
- technological features (for example data of materials or tolerances) can be utilised.
- The model of the product can also contain information in the form of
- manufacturing objects (in the data-added sub-programs for manufacturing a specific geometry) or
- wizards (the software suggest the possible manufacturing methods and the user chooses the appropriate one).

3 Utilizing rapid manufacturing technologies

In this chapter the possibilities to utilize rapid manufacturing technologies for assembly analysis are considered, whether it is possible to rethink assembly design. According to our opinion these types of design tasks, where totally new connector constructions will be designed, would be excellent for testing the advantages of rapid manufacturing processes. Also the specialized requirements of the parts of the assembly support the ideas of rapid manufacturing. Some major design rules to create reasonable and applicable products are according to [4] as follows:

1. Use the advantages that are included in the rapid manufacturing processes.
2. Do not build the same parts just with other processes. Take the time to rethink the whole assembly, reduce it to the functionality and then go straight forward to the integrated freeform design.
3. Do not consider traditional mechanical design principles. There is no need to think about sizes of prefabricated materials, coordinate systems and some possible symmetric axis for the machining.
4. Reduce the number of parts in the assemblies by intelligent integration of functions. For example, joints and flexible areas can be built in one step. This greatly reduces the assembly costs.
5. Take a look if there are bionic examples that fit to your tasks as these can give a hint towards the design of better solutions.
6. Feel free to use freeform designs; they are no longer difficult to produce. We are working on advanced design tools for 3D software to support your wish to develop towards design for rapid manufacturing.
7. Optimize your design towards highest strength and lowest weight. The most important design rule is to use as little raw material as possible and because of this as little energy as possible. Think parts as a connection between two or more functions with the required strength and optimized weight.
8. Use undercuts and hollow structures if they are useful. Do not waste time thinking about a design and how it could be machined or cast.
9. Do not consider tooling, because it is no longer needed. All parts and forms for casting can be generated in one step without planning and designing tools with a huge amount of time and money. Changes in function and improvements in design are no problem because there is only the set of data to be changed.
10. Meet the loads and stresses by optimal shape. Put some material where it is needed and leave it if it is not needed.

According to [4] the main advantage of the new processes is that the amount of used material has to be taken into account for the production as the highest design priority together with best functionality and the best aesthetic design. Lightweight design does no longer mean that you have to try to cut some edges and make some holes with an enormous effort of machining time, by additional manufacturing sequences and by, very often, difficult operations. Lightweight design means in the understanding of the new processes to save money by using as little raw material as possible to provide the parts with the required strength to withstand all forces and stresses that could be applied. The other main advantage is to save assembly time and minimize the risks of assembly errors by reducing the number of needed parts for the specified functionality. The designer has to rethink their approach towards the best solutions for the given task.Typically a rapid manufacturing processes work directly with 3D CAD data. The 3D-modelling process includes typically the following steps [4]:

1. Input of CAD data, input of boundary conditions, measurements and fixing points.
2. Create a surrounding solid.
3. Subtraction of the solids.
4. Cutting clear the needed volume.
5. Definition of fixing points.
6. Optimisation by FE analysis.
7. Mirror the part and export to a STL File.
8. Build the part.

Usually the steps 2-7 can be performed semi-automatically by software. On practical example of a successful assembly design is briefly presented in Fig. 3.1 where both the old and a new construction of mixing device are presented. Notice, that the new construction is actually no more an assembly but a simple machine part. In our case, pure brainwork was used to develop a more sophisticated connector construction from the point of view of easy assembly. However, if a "clever" RP-software is available it will make this work easier and faster.

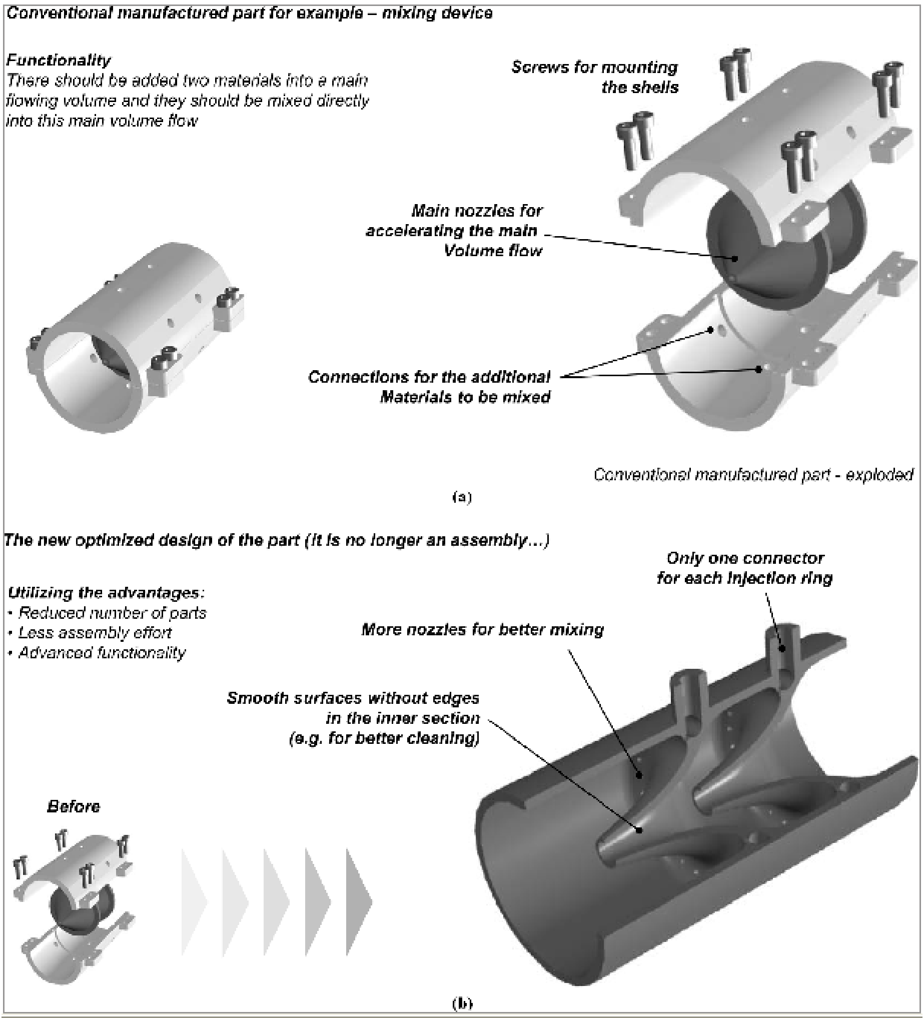

Figure 3.1. Example of a successful construction design by utilizing rapid manufacturing technologies [4].

4 Electrical requirements and electrical safety

The most important requirements for the motor feeder cable junction are as follows:

- the grounding must be electrically strong enough to ensure electrical safety
- the motor feeder cable connection has to be robust to provide enough tensile strength
- the grounding must be good also on high frequencies, preferably a 360 degree grounding and the motor feeder cable must of a suitable type for this type of grounding connection
- the grounding must be easy-to-assemble
- the size of the geometry depends on the diameter of the motor feeder cable, thus the size of the motor

Although the cable junction should also clamp the cable to provide enough tensile strength, the phase conductors should not get squashed by the grounding connection. The most common grounding implementations are presented in Fig. 4.1. In order to ensure good performance in an electrical mean especially in converter drives, the grounding of the cable should be connected 360 degrees around the cable, [2].

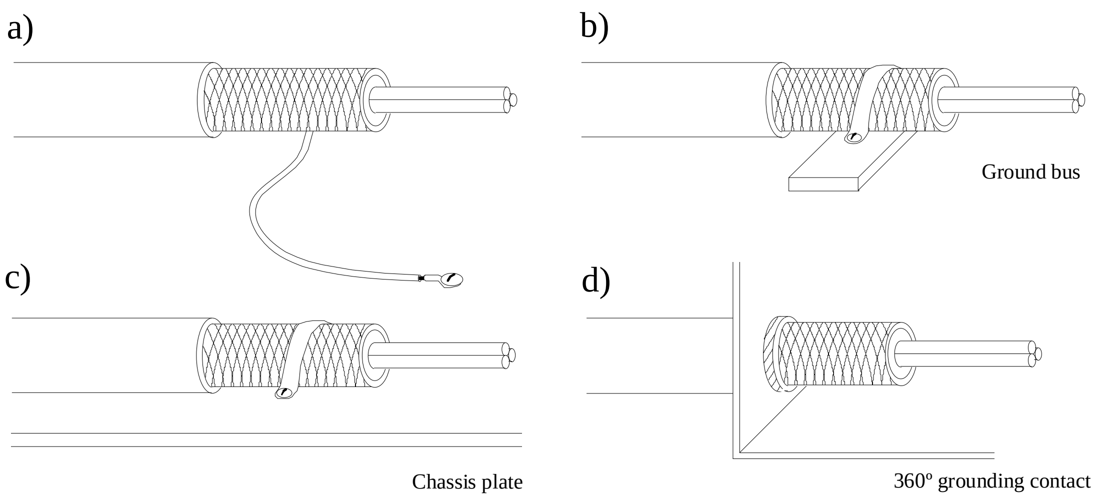

Figure 4.1. Common grounding implementations: a) The grounding is carried out using a separate grounding conductor or by separating the shield around the conductors and connecting it to a grounding terminal. This type of grounding is inadequate to be utilized in a converter drive. The shield of the power cable is connected to a ground bus b) or the chassis plate c) using a grounding loop. This type of grounding is acceptable in converter drives. The ideal grounding is shown in d), where the grounding contact is a symmetrical 360 degrees grounding. The cable gland proposed implements a similar grounding contact as shown in d).

In converter drives, the feeder cable should be of a suitable type in order to establish conditions for a good grounding connection, namely for example MCMK. The recommended principal geometry of the motor cable is presented in Fig. 4.2. It consists of symmetrical phase conductor geometry, insulations, and shield, which also acts as the grounding conductor. Utilizing this type of a feeder cable, it is possible to achieve a 360 degree grounding connection.

The design of the cable gland prototype was based on these requirements in addition to requirements for easy manufacturing and assembly. In a typical motor junction box, the cable gland just fastens the feeder cable to the box, and all the connections are

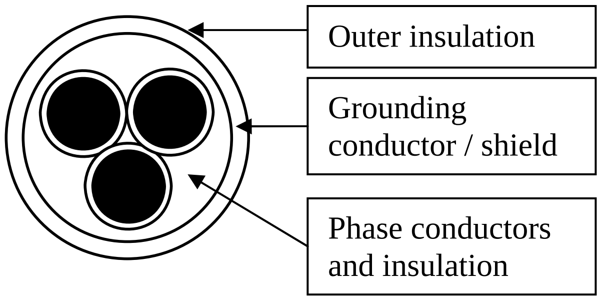

Figure 4.2. The recommended geometry of the motor cable in frequency converter drives. The cable consists of symmetrical phase conductor geometry, insulations, and shield, which also acts as the grounding conductor. For example, the MCMK cable has this type of geometry.

made inside the box. In the approach presented, the phase conductors go through the gland inside the junction box, but the grounding connection is made 360 degrees in the gland in order to ensure EMI performance. Therefore, the gland must be fastened to the junction box and it must be of an electrically conducting material.

In contrary to the traditional grounding solutions, the gland presented provides a 360 degree symmetrical grounding system, which is also the optimal solution from an EMI point of view and is eligible on the high frequency content generated by the operating drive. The performance of the grounding connection can be verified by measuring the electrical performance of the drive under operation. The performance should be measured using a conventional grounding solution and compared to measurements carried out utilizing the EMC cable glands to be verified.

In the design, the cable is stripped, phase conductors are threaded through the cable gland and the shield of the cable is placed on a conical part of the gland. The grounding connection is tightened using a fitting lock ring and outer covering. In addition, the cable can be secured using a standard rubber cable gland, which can be attached to the outer covering to provide more tensile strength. The parts have only standardized threads and only a wrench is needed when assembling the gland. The design is presented in Figures 7.1–7.6.

5 Electromagnetic compatibility and existing EMC cable gland solutions

Typical motor junction boxes do not incorporate cable glands, which would provide good electrical performance in terms of electromagnetic compatibility as the proposed design. Although there are no good existing solutions, however, there are EMC-screened cable glands in the market, which provide symmetrical 360 degree grounding. Many of these glands are typically lightweight solutions used for signal cables instead of power cables. Also, most of these commercial solutions have for example spring-loaded grounding contact and the installation of them is more difficult. Also, these glands consist of many materials, for example brass alloys and nickel plated copper, and have several manufacturing stages. Two examples of these commercially available EMC-screened cable glands are shown in Table 5.1, along with a list of disadvantages of the construction.

Table 5.1 Commercially available EMC-screened cable glands.

	Disadvantages of the construction - possible problems of the reliability of the grounding with relatively thin flat springs - number of part is relatively high, which increases both manufacturing and assembly stages of the cable gland itself - possible ageing problems of the polymer parts - this type of cable gland not the best for electrical drive - possible problems of the fixing of the nickel coating
	Disadvantages of the construction - the construction of the gland is geometrically closed after the first try to make the joint in the cable (it is practically impossible to loosed the assembly afterwards) - the reliability of the shoulder of the locking component is critical - possible ageing problems of the polymer parts - possible problems of the fixing of the nickel coating

6 Required material and mechanical properties

In this chapter the material selection of the turned prototype and the possible metal alloys for casting and moulding are discussed.

6.1 Strength

It can be assumed that mechanical loading due to use and assembly are relatively small.

6.1.1 Loading cases due to use and assembly

If steels S355 or cast irons GJL300 are used, the yelled-strength is high enough to withstand all the thinkable loads during the normal use. If cast irons are used, the lowest temperature must limited to avoid the possible break-downs of the connector due to materials brittle behaviour in low temperatures.

6.1.2 Loading cases during the manufacturing stages

Because of the wall thickness of the inner hub is at its smallest in the end of the part, the turning forces should limited during the turning stage of the conical geometry. This is a typical example where the critical loading case arises from manufacturing processes and not from traditional outer loading reasons.

6.2 Other properties

6.2.1 Structural stiffness

The required structural stiffness of the connector is ensured by combining the modulus of the elasticity (S355/210000 MPa, GJL300/130000 MPa) of the material with the rigid geometry of the connector against the main loading direction.

The design of the cable gland is presented in Figures 7.1–7.6.

7 DFMA-aspects of different manufacturing technologies

In this paper, following technologies are discussed: traditional turning, precision and centrifugal casting, and rotation moulding. Main guidelines for manufacturing consist of three aspects. The required tolerance grade is not higher than IT7, which is easy to achieve by using any of the manufacturing technologies mentioned above. The required threads, their geometry and all required grooves can be manufactured and finished with fully standardized cutting tools.

To make the assembly stages easier following design steps have been followed:

1. use of self-alignment principles of components
2. minimized need of different tools
3. minimized number of directions for assembling the components
4. minimized number of motion types used for assembly stages
5. ergonomic aspects

Self-alignment of components is arranged by using conical geometry of the inner hub. Only adjustable wrench is needed for fitting the components. All three parts are assembled from one direction only. Two motion types – namely pushing and rotating – are needed during the assembly. In addition to this, size of the components fits well to the ergonomics.

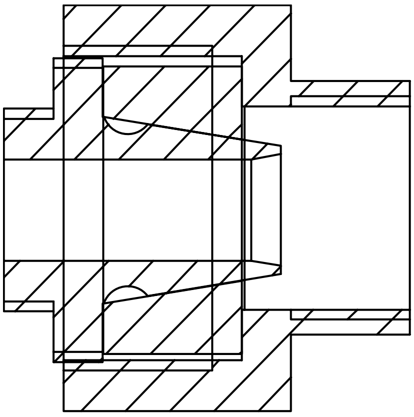

Figure 7.1. The cable gland design consisting of the gland, lock ring and an outer covering fitted together.

Figure 7.2. The prototype of the cable gland and the lock ring. The gland is screwed to the motor junction box and the outer covering (not shown) is screwed to the gland. Both parts can be tightened using standard wrench sizes.

Figure 7.3. The prototype of the cable gland and the lock ring. The lock ring secures the grounding connector between the conical part of the gland and the lock ring.

Figure 7.4. The feeder cable is fitted in the gland. The phase conductors are threaded through the gland and the grounding conductor is fitted between the conical part of the gland and the lock ring. The outer covering, which tightens the connection, along with the possible standard cable gland is not shown.

Figure 7.5. The prototype including the gland, the lock ring, and the outer covering. The standard cable gland used to secure to cable is not shown.

Figure 7.6. Fully assembled prototype, including the gland, the lock ring, the outer covering, and the standard cable gland used to secure the motor cable.

7.1 DFM-aspects of turning

Following geometrical improvements have been designed to the construction to make turning stages easier.

- end grooves of the conical hub
- end grooves of threads
- practically no specialized requirements of surface roughness
- full sized thread through the body of the component

The end groove of the conical hub gives also space for the end of the connecting grounding conductor. This is a typical example in which functional and manufacturability aspects can and must be integrated. Naturally, any thread should end directly to a sharp corner. In this construction, two ways to avoid this mistake have been used. In the inner parts, end grooves were used even though they are additional manufacturing stages. But, in the body of the connector it was possible to use full length thread through the component. By normal turning process, the surface roughness of 0.8 micrometers can be easily achieved, which is enough to ensure the performance of the connector. As well known, turning is however an expensive manufacturing technology, no matter how well DFM-aspects are considered. For that reason, the possibilities to use casting and moulding processes for mass production have been studied.

7.1.1 Some basic rules of DFM for turning

1. Use geometries suitable directly for standardized tools for tuning (see Fig 7.7).

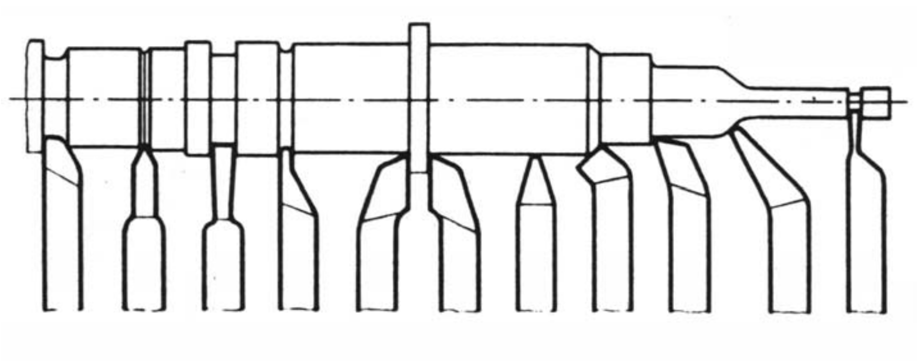

Figure 7.7. Standardized tools for turning.

2. Use chamfers instead of fillets in the end corners of a shaft (see Fig. 7.8).

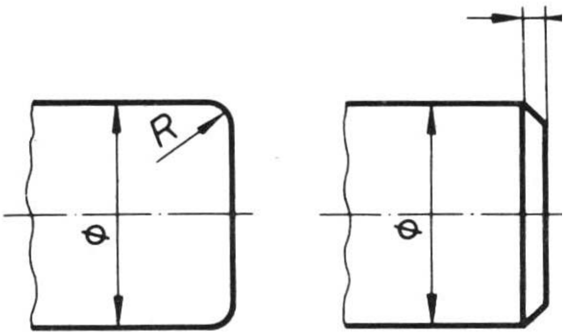

Figure 7.8. The end corner of a shaft should be ended to a chamfer instead of a fillet.

3. For turning use chamfers instead of fillets or straight corners also for the inner geometries in the end-corners of a shaft (see Fig. 7.9).

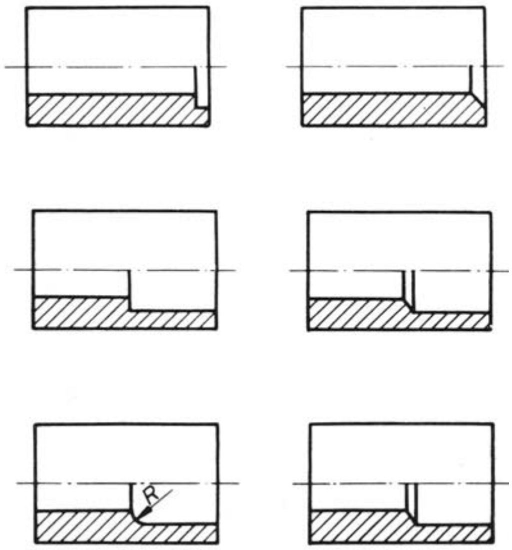

Figure 7.9. Easier turning geometries presented on the right.

7.2 DFM aspects of casting

In this case, two main aspects has been discussed: can the required dimension accuracy be obtained by using any casting processes and is it possible to take advantage of the relatively simple geometry the connector if casting processes can be utilized.

7.2.1 Precision casting

Modern precision casting fulfils easily all the quality requirements of the connector. Like presented in the technical documents of the connector, relative large values of pitch of each thread are used and no closed and small geometries of grooves have been designed.

7.2.2 Centrifugal casting

In our case, precision casting should be applied to centrifugal casting process. This is possible because of the following items:

- almost symmetric geometry around the longitudinal axis of the connector
- relatively thick wall thicknesses of each component
- open geometry in the direction of the longitudinal axis of the connector
- no specialized requirements of the material (any cast iron or steel could be used)

According to our opinion, it is hard to avoid any machining stages after the casting process if specialized geometries are needed for tightening tools. Because of the requirements presented in electrical safety standards, this manufacturing stage is hard to avoid as well. The critical stage of the casting process is to adjust the wall thickness of the conical geometries. Because the minimum wall thickness is always larger than 1.5 millimetres, the geometrical requirements can be met by using precision casting procedures. One aspect worth noticing is that modelled geometry of the turned components can be used as drafts for modelling moulds and final geometry for casting.

7.2.3 Principles of centrifugal casting

The geometry of the components of the connector design fit well to centrifugal casting process. In centrifugal casting, a permanent mould is rotated about its axis at high speeds (300 to 3000 rpm) as the molten metal is poured. The molten metal is centrifugally thrown towards the inside mould wall, where it solidifies after cooling. The casting is usually a fine grain casting with a very fine-grained outer diameter, which is resistant to atmospheric corrosion, a typical situation with pipes. The inside diameter has more impurities and inclusions, which can be machined away.

The minimum wall thickness for easy casting is about 2 mm and it is not a problem for our construction. However, the tolerances might be as poor as a few millimetres depending on the size and geometry of the product, which means that in some cases machining processes are necessary. Also the surface roughness of the product is not better than the average in engineering. Typical materials that can be cast with this process are iron, steel, stainless steels, and alloys of aluminium, copper and nickel. Two materials can be cast by introducing a second material during the process.

A typical comparison (see e.g. [5] is made between centrifugal and static vacuum assisted casting if small parts are to be manufactured (as in our case). Centrifugal casting has two weak points: high poured liquid metal turbulence and high pressure in the mould both produced by the centrifugal force. Both these features are unfavourable, even if high pressure facilitates complete form filling. High turbulence increases the probability of gas entrapment and favours the formation of gas porosity. The probability of the occurrence of gas porosity is also increased by the fact that, in centrifugal casting machines, perforated moulds are not used and, even if a suction system is available, suction takes place only through the mould bottom. So, outflow of the gas contained in mould cavities will be slower than in a vacuum assist casting machine.

7.2.4 Applying DFM(A)-Approaches for casting

In this chapter two ways to fulfil the DFM-requirements of casting are compared. First the traditional design rules are presented, which are usually regarded as an optimum solution for DFM-problems. To find an objective point of view this approach is compared to a new one, which is based on a conceptual framework for designing metal casting presented in [6].

7.2.4.1 Simple design rules for casting

Some typical rules of thumbs for designing castings for easy manufacturing are listed below. The numerical values depend a lot on the selected casting processes and used metal alloys and therefore they should be regarded only as guiding values.

1. Remember to establish the required draft angles.
2. Try to keep casting sections to a uniform thickness, avoid having several section meeting at one point.
3. Avoid heavy isolated sections.
4. Avoid sharp internal corners; a small radius of 0,5 mm minimum is preferred.
5. Most hole can be cast at clearance, reaming or tapping sizes.
6. Indicate the amount of machining allowance if required.
7. Casting feed pads are normally placed at the heaviest section, in a flat area for ease of removal.
8. A 0.3 mm feed witness is usually left on the casting after linishing, but can be removed if required.
9. Avoid deep narrow blind channels or pockets if possible.
10. Select a suitable alloy from the standard alloy ranges cast.
11. Section sizes of less than 1,0 mm can be cast locally, but preferably sections of >1,5 mm are preferable.

7.2.4.2 New DFM(A)-aspects of metal casting

A lot of work has been done to find an optimum way to design products, which would be appropriate for casting. For example, in [6] researchers have focused their interest in finding the conceptual framework for designing metal castings. According to [6] “rules of thumbs” abound the attempt to define fillets, radii, changes of casting section, minimum section thickness, tolerance capability, etc. Yet, there are regularly casting designs that seem to violate these “rules” successfully. These designs typically have combinations of geometry that should not work, but that do.

Based on [6] the elements of conceptual framework can be presented as follows:
Four important physical characteristics affect the castability and performance of any given casting alloy. These are as follows:

- Fluid life
- Solidification shrinkage
- Slag and/or dross formation tendency
- Pouring temperatures.

Each of these characteristics varies widely among alloys and are significantly different among similar alloys. Differences among these four physical characteristics significantly affect the geometry of well designed castings.

It is also important to understand two important mechanical characteristics affecting the stiffness of any give casting design:
- Modulus of elasticity
- Section modulus

The former is a function of the stiffness of the alloy itself and the latter is a function of stiffness from the casting's geometry. It is necessary to understand that the six characteristics mentioned above affect important variables in designing, producing and using metal castings. These variables include the following:

- Casting method
- Design of casting sections
- Design of junctions between casting sections
- Internal integrity required
- Dimensional tolerances and extent of near-net shape requirements
- Casting geometry as a tool

Casting geometry is the most powerful tool to improve the castability of the alloy and to increase the mechanical stiffness of the casting. Carefully planned geometry can offset alloy problems in fluid life, solidification shrinkage, pouring temperature and slag/dross formation tendency. Section modulus from geometry has the power to offset problems with lower modulus of elasticity.

In [6] the key-finding is that engineers should get stuck with the traditional concepts and tools of designing castings. For example many good product ideas could be destroyed if the rules of thumbs are obeyed word by word. This might lead to so-called “simple, orthogonal shape thinking” : such as building blocks from mill shapes like plates, bars, tubes, I-beams, other kinds of extrusions of constant cross section, etc. However, the use of these shapes limits metal casting's power of infinite shape variability. According to [6] casting geometry can be so much more free-flowing than orthogonal, extruded, and rotated shapes. The authors of this report fully agree with the opinions presented in [6], which suggest utilizing “systems approach style to design thinking of castings”. Such an approach encompasses everything, from the original need for a mechanical or structural element, to molten metal flowing into a shape, to the rough casting right out of the mould or die, through casting finishing requirements, secondary processing in the foundry, secondary processing at a subcontractor and/or the customer's plant, testing, assembly, and final use and abuse of the product which contains the casting.

7.3 DFM aspects of rotational moulding

Basically the DFM-aspects presented for centrifugal casting are valid also for rotation moulding. The main difference comes from the material selection. Because the moulding process is based more on the flow-properties of the material, the proper filling of the mould during the process must be ensured. This might lead to change of the material alloying. During the coming research stages time could be found to focus on optimizing the casting alloy. By utilizing a very typical DFM(A)-questionnaire (see Table 7.1, [7]) it is possible to compare different connector constructions according to their manufacturability and assembly properties. Ticking in table 7.1 is made for the construction presented in this paper.

Table 7.1 Questionnaire for easy assembly

Question (assembly analysis)	Answer
1. Direction	☒ x ☐ y ☐ z
2. Plane	☐ xy ☐ yz ☒ xz
3. Motion	☒ push ☐ pull ☒ rotate
4. Alignment	☒ self ☐ with different components ☐ must be adjustable

7.4 Basic steps of the assembly analysis

The assembly analysis carried out during this research consists of the following stages:

1. Handling and storage of work piece
   - Recognition
   - Gripping
   - Moving
2. Positioning of the work piece
   - Direction
   - Location
3. Joining stages of the work piece
   - Technologies based on friction, part geometry or use of joining consumables
4. Fine adjustment and backlash control of the assembled components
5. Inspection of the assembly

7.5 Required changes due to DFM(A)-rules

During the manufacturing process, two aspects were discussed:

- Changes of the turning stages
- Standardization of the joining dimensions
- Optimization of material thicknesses

The length of the thread for the assembling the cable gland was lengthened to go through the hole diameter (compare the original dimensioning in Fig. 7.1). The thread in the end of the cable gland needed a groove to make it easier to turn the required thread length. The following ideas could be applied to increase the utilization of valid standards:

- The milled sizes for tightening the connector with a wrench could be adjusted to follow standardized dimensions
- The pitches of each thread could be equalized
- Outer diameters of the components could be selected closer to the diameters of available bulk material

Because any strength calculations have not been made, the dimensions of the construction are based on mostly based on ergonomic and assembly factors. It is obvious that wall thicknesses can be reduced if it is necessary to make a lightweight construction. However, the selected dimensions are excellent for easy handling of the connector part. In addition to the changes mentioned above, a relatively large sized groove was turned in the end of the conical geometry of the cable gland in order to fit the ends of the grounding conductors. During the design it was noticed that the length of the outer covering has to be increased to produce enough space for the pressed cable end. All the changes mentioned above were carried out during analyzing and designing process of the connector and the first prototype was therefore ready to use. This example shows the importance of detailed DFM(A)-analyzes within a group of experts on all important branches of science (in this case, electrical engineering and mechanical engineering).

8 The future

During the future research project the possibilities to utilize some rapid manufacturing technologies for the advanced design of the connector e.g. by applying the principles presented in [4] are studied. The research team has been working since year 1999 at LUT. Some interesting results of DFMA-projects have been published at earlier IMC-conferences for example in [8] and [9] and a specialized series of publications has been opened at LUT, see for example [10]. Also, a compatible motor junction box to be utilized with the proposed cable gland has been designed and constructed, see Appendix I. The junction box, along with the advanced cable gland will be assembled to an existing frequency converter drive to verify the electrical operation of the cable gland by measurements. The research group aims to carry out further development in co-operation with a Finnish connector manufacturer to develop a commercial product.

9 Conclusion

To make the assembly stages of the studied connector easier the following design steps have been followed: 1) use of self-alignment principles of components, 2) minimized need of different tools, 3) minimized number of directions for assembling the components, 4) minimized number of motion types used for assembly stages and 5) ergonomic aspects. By normal turning process, the surface roughness of 0.8 micrometers can be easily achieved, which is enough to ensure the performance of the connector. Turning is, however, an expensive manufacturing technology, no matter how well DFM-aspects are considered. For that reason, the possibilities to use casting and moulding processes for mass production have been studied. In the case of the studied connector, precision casting should be applied to centrifugal casting process. It has been proved that modern precision casting fulfils easily all the quality requirements of the connector. According to our opinion a detailed DFM(A)-analysis can be carried out by utilizing a specialized DFM(A)-questionnaire.

References

[1] Bartolucci E.J., Finke B.H., "Cable Design for PWM Variable-Speed AC Drives," IEEE Trans. on Ind. Applicat., vol. 37, pp. 415-422, March/April 2001.

[2] Bentley J.M, Link P.J., "Evaluation of Motor Power Cables for PWM AC Drives," IEEE Trans. on Ind. Applicat., vol. 33, pp.342-358, March/April 1997.

[3] Ström, J-.P., Eskelinen, H., Varis, J.P., Silventoinen, P., "Manufacturability and Assembly Aspects of an Advanced Cable Gland Design," IMC24, Proc. of the 24th International Manufacturing Conference, 29th - 31st August 2007, Waterford, Ireland, pp. 721-728, ISBN 0-9556468-0-5.

[4] Becker R., Grzesiak A., Henning A., "Rethink assembly design," Assembly Automation , Volume 25, Number 4, pp. 262-266, 2005.

[5] Faccenda, V., "Investment casting: Centrifugal static vacuum assist?" Aosta, Italy, http://www.gold.org/discover/sci_indu/GTech/1998_23/Casting.pdf (Accessed 20th September, 2007).

[6] Gwyn, M., "Conceptual Framework for Designing Metal Casting," PELTON Casteel, Inc.

[7] Eskelinen, H. et al., "Microwave Mechanics Components," Artech House, New York / London, 3 / 2003, ISBN 1-58053-368-X.

[8] Eskelinen H., Heinola J.-M., Varis J.P., "Manufacturing of modified SMA-connector made of Cu-of copper to fulfil mil-standard specification," IMC22, Proc. of the 22nd International Conference, Dublin, Ireland, 31.8.-2.9.2005, pp.123-129, ISBN 0-9551218-0-9.

[9] Eskelinen H., Varis J.P., Ström J.-P. Heinola J.-M., "DFM(A)-aspects for an E-Plane Waveguide Ring Resonator Design," 23rd International Manufacturing Conference (IMC23), 30.8-1.9.2006, University of Ulster, Northern Ireland.

[10] Eskelinen H., Lätti K.-P., Silventoinen P., "DFM(A)-aspects for an SMA Connector Design," LUT 2004, Department of Mechanical Engineering, Research report 53, ISBN 951-764-946-0, ISSN 1459-2932, 40 pages.

APPENDIX I - The motor junction box design.