Design of Machines and Structures, Vol. 4, No. 1 (2014), pp. 57–64.
https://doi.org/10.32972/dms.2014.006

ANALYSIS OF GEAR-DRIVES AND SEARCHING OF NOISE REDUCTION POSSIBILITIES WITH THE HELP OF GRAPHS

FERENC SARKA–ÁDÁM DÖBRÖCZÖNI
University of Miskolc, Institute of Machine and Product Design
3515, Miskolc-Egyetemváros
machsf@uni-miskolc.hu, machda@uni-miskolc.hu

This paper shows a new approach of gear-drive analysis. The aim of the new approach is that through the description of gear-drives with graphs ensuring an opportunity for parts and machine elements having new properties. The reason for creating parts with new properties is to reduce noise in gear-drives.

1. Introduction

Gear-drives are often used in industry, to make connection between the engine and the machine. Because using them widely, extensive researches were made in the past as in abroad and in Hungary too. In the 18th century the noise is generated by coupling of gears was discovered, but researchers seriously dealing with this problem only in the past 30 years. Load-bearing ability, which is used to be considered as a primary aspect, has been overshadowed by the acoustic attitude and the low noise emission in the designing process of wheel-gears. The significance of strength as an inevitable condition has still not been reduced.

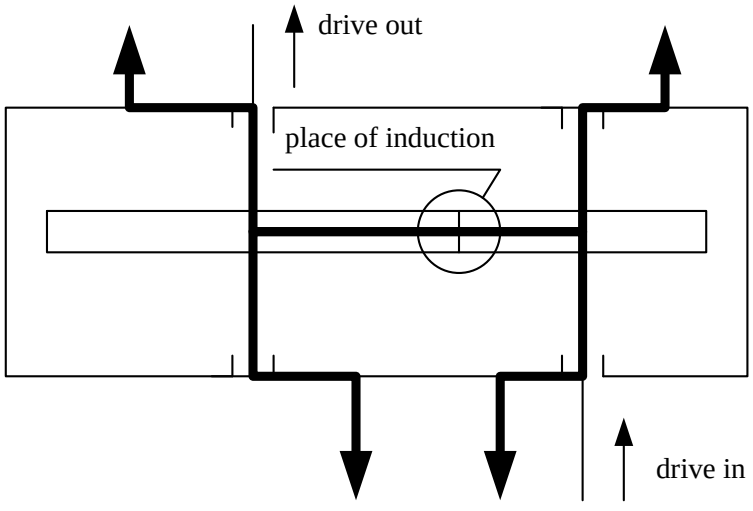


Figure 1: Scheme of single speed gear-box, with primary transmission routes [5]

This paper presents a theoretical method, which introduces how to find opportunities to reduce the noise in gear-drives.

Figure 1 shows the sketch of a one speed gear-drive. In the Figure the main vibration transmission route can be seen with black arrows, which is called *primary transmission route*. The vibration gets from the place of induction to the environment on this route.

2. Transformation of the gear-drive to a graph

With the help of the graph theory an important field of the mathematics the single speed gear-drive, which is shown in Figure 1, can be described shove off from the conventional engineering approach. Handling gear-drive as a graph can help creating new constructional recommendations or parts with new or modified properties. The parts of the drive corresponds to the nodes of the graph, the acoustical connection between the parts corresponds to the edges of the graph. With this kind of correspondence the acoustical behaviour of the gear-drive can be defined as a graph (Figure 2).

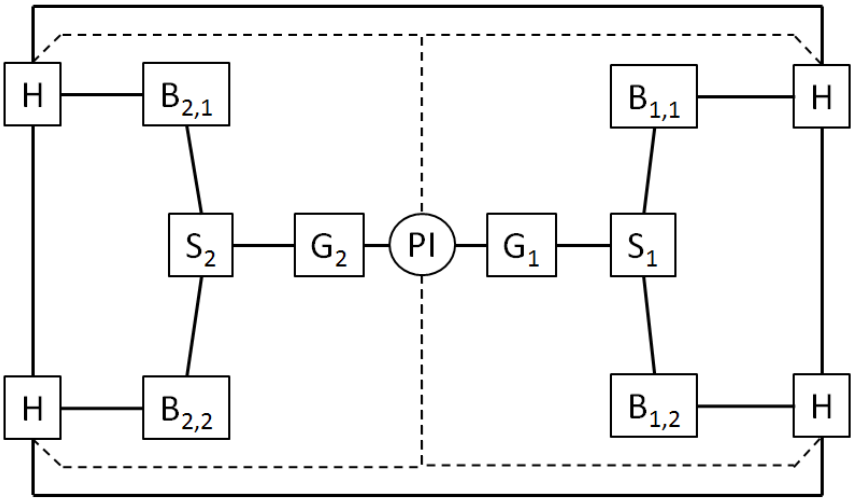


Figure 2: Acoustical connection graph of a single speed gear-drive

The meaning of the signs used in Figure 2:

- G_1: drive gear,
- G_2: driven gear
- S_1: drive shaft,
- S_2: driven shaft,
- $B_{1,1}$; $B_{1,2}$: bearings of the drive shaft,
- $B_{2,1}$; $B_{2,2}$: bearings of the driven shaft,
- H: house,
- PI: the place of induction.

Dashed line in Figure 1 demonstrates the secondary transmission route of the gear-drive. The secondary transmission route is irrelevant on the basis of the practice [3]. The secondary transmission route does not appear in the further discussion. The name of the created graph should be the acoustical connection graph (Figure 2).

3. Describe the graph with matrix

Graphs can be described with the help of matrixes. With the matrix of the acoustical behaviour of a gear-drive the connection between the parts of the drive can be shown with the proper value of logical connection functions. The connection function ($f_{i,i}$) has two values. If the connection is exist the value is 1, if the connection does not exist, the value of the connection function is 0.

A=

	F_1	F_2	…	F_{n-1}	F_n
F_1		$f_{1,2}$	…	$f_{1,n-1}$	$f_{1,n}$
F_2	$f_{2,1}$		…	$f_{2,n-1}$	$f_{2,n}$
…	..	…		…	…
F_{n-1}	$f_{n-1,1}$	$f_{n-1,2}$	…		$f_{n-1,n}$
F_n	$f_{n,1}$	$f_{n,2}$	…	$f_{n,n-1}$	

Figure 3: The acoustical connection matrix of a gear drive in common form

The basis of the creation of the matrix **A** is Figure 2. This figure shows the part of the gear drive and the connection functions between them. F_n means the parts of the gear-drive. All of them embody a sort of function too. It can be registered into the proper places of the matrix if there is, or there is no connection between the parts of the gear-drive. This way defined matrix, should be the acoustical connection matrix (**A**) (Figure 4).

A=

	H	G_1	S_1	$B_{1,1}$	$B_{1,2}$	G_2	S_2	$B_{2,1}$	$B_{2,2}$
H	0	0	0	1	1	0	0	1	1
G_1	0	0	1	0	0	1	0	0	0
S_1	0	1	0	1	1	0	0	0	0
$B_{1,1}$	1	0	1	0	0	0	0	0	0
$B_{,2}$	1	0	1	0	0	0	0	0	0
G_2	0	1	0	0	0	0	1	0	0
S_2	0	0	0	0	0	1	0	1	1
$B_{2,1}$	1	0	0	0	0	0	1	0	0
$B_{2,2}$	1	0	0	0	0	0	1	0	0

Figure 4: The acoustical connection matrix of a single speed gear-drive with helical gears

4. Description of a graph with formula

On the basis of the acoustical connection graph, gear-drives can be described by formulas introducing a new notation. Establishing the formula is implemented by alphanumeric characters and connection signs. This has to be conformist with the acoustical connection graph and the acoustical connection matrix. Observing the acoustical connection graph there are parts that are parallel and there are parts with lined up connection. The sign

of the parallel connection is //. The sign of the lined up connection is. The sign of graph segment: ( ). The acoustical spreading formula can be created after giving the creation rules (1).

$$[(H\text{-}B_{2,2})//(H\text{-}B_{2,1})]\text{-}S_2\text{-}G_2\text{-}G_1\text{-}S_1\text{-}[(B_{1,1}\text{-}H)//(B_{1,2}\text{-}H)] \quad (1)$$

5. Create a modified graph, described with matrix and formula

On the basis of literature dealing with the acoustical behaviour of gear-drives it is declared that the most effective constructional modification place of the gear-drives is to reduce the emitted noise between the source and emission in the primary transmission route. The statement above can be built into the acoustical connection matrix of the acoustical connection graph of a gear-drive introduced in Figure 2. To reduce the emitted noise of the gear-drive such a connection has to be created between each part, which prevents the spread of the vibration and has a good vibration absorbing properties.

The acoustical connection matrix has to be supplemented with new columns and rows. The new supplementation contains the parts between the original parts of the drive. New parts symbolize the obstacle of the vibration spreading. I_i (Isolator) is the sign of a new part. In this case the acoustical connection graph of the drive looks like the one in Figure 5. Uniting the parts of the modified graph on the basis of function merging principle new and acoustically better machine elements can be created. In this case the new property of the part is the vibration isolation. Of course new property not only the vibration isolation can be. In Figure 5 circles show examples for the function merging principle.

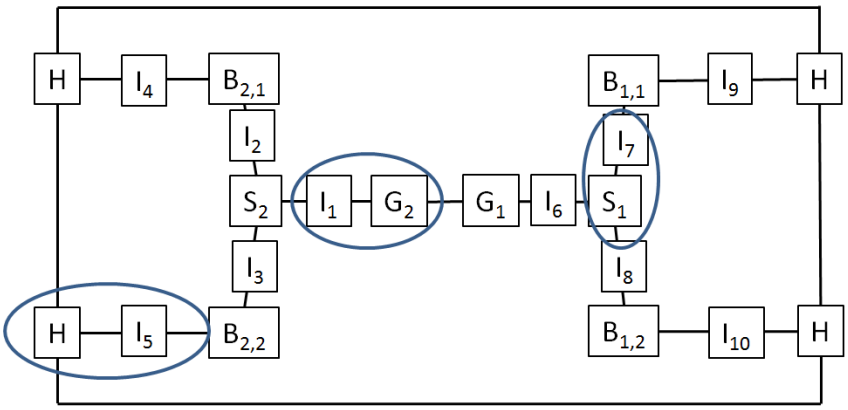


Figure 5: The supplemented acoustical connection graph of the gear-drive, supplemented by vibration isolator parts

Sorting by type the parts of the gear-drive is another way to create the **A** matrix of the graph shown in Figure 5. Gears, shafts, bearings are side by side. With this type of matrix creation can be generated the acoustical connection matrix **A** of Figure 6.

A=

	H	G_1	G_2	S_1	S_2	$B_{1,1}$	$B_{1,2}$	$B_{2,1}$	$B_{2,2}$
H	0	0	0	0	0	1	1	1	1
G_1	0	0	1	1	0	0	0	0	0
G_2	0	1	0	0	1	0	0	0	0
S_1	0	1	0	0	0	1	1	0	0
S_2	0	0	1	0	0	0	0	1	1
$B_{1,1}$	1	0	0	1	0	0	0	0	0
$B_{1,2}$	1	0	0	1	0	0	0	0	0
$B_{2,1}$	1	0	0	0	1	0	0	0	0
$B_{2,2}$	1	0	0	0	1	0	0	0	0

Figure 6: Acoustical connection matrix of a single speed gear-drive operated with helical gears, parts lined up side by side

Supplementing the matrix of Figure 6 with the new parts of Figure 5 a modified acoustical connection matrix of Figure 7 arises. The upper left part of the matrix is the original base matrix (Figure 6), the other three segments of the matrix are the supplementation. If there is connection between the parts of graph in Figure 5 there will be 1 in the matrix of Figure 7. If there is no connection between parts, there will be 0 in the matrix of Figure7. The supplemented acoustical spreading formula can be also created to the modified/supplemented gear-drive (2).

$$\{[(H\text{-}I_5)\text{-}(B_{2,2}\text{-}I_3)]//[(H\text{-}I_4)\text{-}(B_{2,1}\text{-}I_2)]\}\text{-}S_2\text{-}(I_1\text{-}G_2)\text{-}(G_1\text{-}I_6)\text{-}S_1\text{-}\{[(I_7\text{-}B_{1,1})\text{-}(B_9\text{-}H)]//[(I_8\text{-}B_{1,2})\text{-}(I_{10}\text{-}H)]\} \quad (2)$$

With the examination of the upper right or lower left part of the matrix of Figure 7 it is declarable that each ones ("1") in the matrix signs a new machine element with the help of the function merging principle. New constructional recommendations can be given on the basis of supplemented acoustical connection matrix **A'** by selecting a cell, that contains one (Figure 7).

A' =

	H	G_1	G_2	S_1	S_2	$B_{1,1}$	$B_{1,2}$	$B_{2,1}$	$B_{2,2}$	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10
H	0	0	0	0	0	1	1	1	1	0	0	0	1	1	0	0	0	1	1
G_1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
G_2	0	1	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
S_1	0	1	0	0	0	1	1	0	0	0	0	0	0	0	1	1	1	0	0
S_2	0	0	1	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0
$B_{1,1}$	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0
$B_{1,2}$	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
$B_{2,1}$	1	0	0	0	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0
$B_{2,2}$	1	0	0	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0
I1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
I2	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
I3	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
I4	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
I5	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
I6	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
I7	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
I8	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
I9	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
I10	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0

Figure 7: Supplemented acoustical connection matrix of a single speed gear-drive

6. Creating the isomorph version of the acoustical connection graph

Creating the isomorph version of the single speed gear-box shown in Figure 1 described by the acoustical connection graph introduced in Figure 2 and 5 the graph in Figure 8 arises, where the starting point is the place of induction (PI) and the end point is the house (H).

This kind of graph is a directional, circle-free graph. The name of this graph should be isomorph acoustical connection graph. Of course this kind of isomorph graph can be modified by new parts, as shown in the graph of Figure 5 (Figure 8).

The new parts of the graph in Figure 9 may not only be noise reduction parts, but there should be parts with other properties too. The sign of the newly build in parts is I_i again. In this case of graphs there is an opportunity to weight each connection, namely taking account of the proper importance of each connection.

In Figure 8 the starting point of the graph is the PI (place of induction) node, and the end node is the H (House) node. The place of the induction is the coupling/meshing of the gears. In the graph of Figure 8 and Figure 9 there are four different admittance ways to get from the start (PI) to the finish (H).

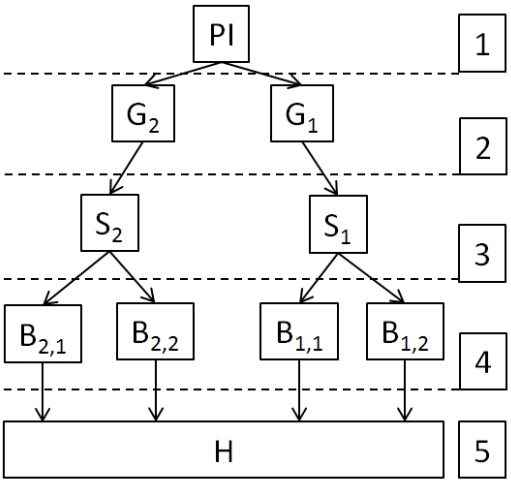


Figure 8: Realigned acoustic connection graph of a single speed gear-drive

The number of the admittance ways of the graph on Figure 8 is the same as the primary transmission routes of the original gear-drive. Multi-level can be distinguished in the graph. The higher level of the graph is examined the closer is the starting point of the graph that is the place of induction.

Results can be reached in noise reduction (adding I_i nodes) in the whole gear-drive only then when the reduction hits every connections of a single level in the isomorph graph. In that case when the modification happens only in the right side admittance way of level 2 several expectations are not realised, because on the left hand side admittance way the

property that should be modified can go through without any changes. It is declarable too, that the modification touches more levels it has more effect to the whole gear-drive.

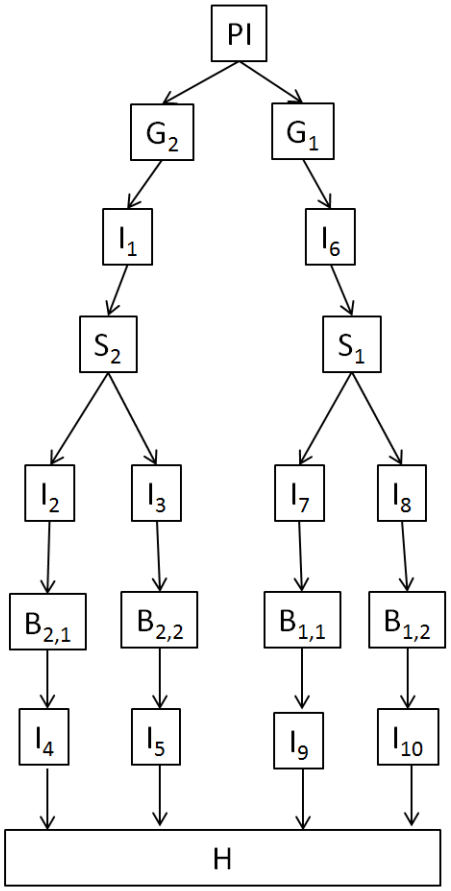


Figure 9: Supplemented realigned acoustic connection graph of a single speed gear-drive

The position of the round brackets in formula (2) can be varied; it depends on which part is the modified one. There is an example of the round brackets translocation in formula (3).

$$\{[H\text{-}(I_5\text{-}B_{2,2})\text{-}I_3]\|[(H\text{-}I_4)\text{-}(B_{2,1}\text{-}I_2)]\}\text{-}S_2\text{-}(I_1\text{-}G_2)\text{-}(G_1\text{-}I_6)\text{-}S_1\text{-}\{[(I_7\text{-}B_{1,1})\text{-}(I_9\text{-}H)\|(I_8\text{-}B_{1,2})\text{-}(I_{10}\text{-}H)]\} \quad (3)$$

The examination method of acoustical connection graph that has a purpose to create parts with new properties can be broaden to other type of gear-drives beyond the single speed gear-drive.

7. Summary

The method that was shown in this paper can gives an opportunity to the designer to reveal new constructional modification that evaluate noise reduction in gear-drives with new properties of the modified parts. Partly giving up traditional mechanical engineering design aspects this is a possibility for modifying gear-drives not only referring to the acoustics.

Acknowledgement

The research work presented in this study based on the results achieved within the TÁMOP-4.2.1.B-10/2/KONV-2010-0001 project and carried out as part of the TÁMOP-4.1.1.C-12/1/KONV-2012-0002 "Cooperation between higher education, research institutes and automotive industry" project in the framework of the New Széchenyi Plan. The realization of this project is supported by the Hungarian Government, by the European Union, and co-financed by the European Social Fund.

References

[1] Åkerblom, M.: Gear Noise and Vibration – A Literature Survey. Trita-MMK, 2001.
[2] Andrásfai B.: Ismerkedés a gráfelmélettel. Tankönyvkiadó, Budapest, 1985.
[3] Dömötör F.: Rezgésdiagnosztika II. kötet. Dunaújvárosi Főiskola Kiadói Hivatala, Dunaújváros, 2010.
[4] Kováts A.: Gépszerkezettan (Műszaki akusztika). Tankönyvkiadó, Budapest. 1988.
[5] Sarka, F.–Döbröczöni, Á.: Directives of Designing Machines with Low Noise Emission. Advanced Engineering, Vol. 5, No. 2, 2011.
[6] Takács Á.: Számítógéppel segített koncepcionális tervezési módszer. PhD-értekezés, Miskolc, 2009.
[7] Åkerblom, M.: Gear Geometry for Reduce and Robust Transmission Error and Gearbox Noise. Trita-MMK, 2008.