TRANSMISSION SIMULATION WITH ADAMS

Interface ECS Software GESIM to ADAMS and Gear Module for ADAMS

Dipl.-Ing. **Josef Leitner**, Engineering Center Steyr GmbH, Austria

Abstract

The paper describes the interface of the transmission analysis Software GESIM to ADAMS and the gear module for ADAMS.

The software GESIM developed by the Engineering Center Steyr (ECS) is a tool for the analysis of gears, shafts and bearings in transmissions. Within GESIM the gears, shafts and bearings are defined, dimensioned and analyzed for geometry, strength and fatigue life. The command files written by the interface module GESIM ADAMS represent virtual prototypes as 3D models of the driveline elements. They can directly be used for natural frequency analysis, vibration analysis or for investigations of deflection of shafts under dynamic loads.

For vibration and noise analyses a detailed dynamic model of a cylinder gear pair is in development. This model includes the variable stiffness of the gear mesh along the line of contact, the non-linear characteristics of rolling element bearings and the flexibility of shafts and housings. The results of the model are the excitations at the bearing positions in the housing. These can be used as input data for noise analyses of the housings by FEM.

1 INTRODUCTION

The demands on the development concerning fast proceedings and high precision of the first prototypes already are constantly increasing.

Usually there are specific tools for the various analysis tasks to be performed during the development of a transmission.

There are specific tools for the dimensioning of the transmission elements, in case of Engineering Center Steyr (ECS) it is the program package GESIM. After the dimensioning of the elements the dynamics of the transmission and the vehicle using the transmission have to be investigated. For this purpose again a model of the transmission has to be set up, in our case an ADAMS model.

It is obvious that a data exchange and an automatic model generation has clear advantages: it speeds up the development and it avoids possible errors. Furthermore there is a standardization of the designations of the elements as they are set by the program. The Engineering Center Steyr has experience in integration projects as it has set up the cylinder gear integration published in /7/, /8/ and /9/.

For specific tasks like detailed vibration or noise analyses an accurate model of a gear mesh taking into account the essential excitations has to be set up. This is done by a model considering the varying stiffness characteristics along the line of contact. In this model the nonlinear bearing stiffnesses are considered as well as the elasticities of shafts and housings.
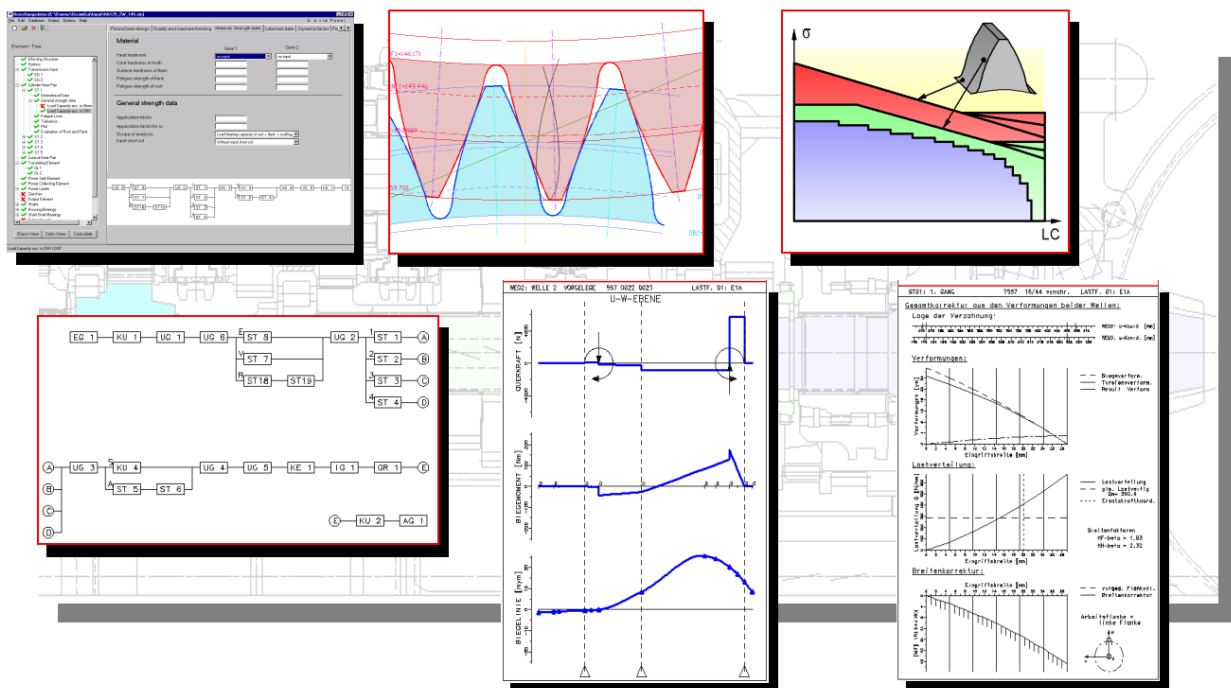

Fig. 1: GESIM Overview

2 GESIM – ADAMS

2.1 Transmission Simulation Software GESIM

The software GESIM developed by the Engineering Center Steyr (ECS) is a tool for the analysis of gears, shafts, bearings, synchronizers and splines in transmissions and for the generation of gear drawings, fig. 1.

GESIM has a modular design and a windows surface. The input is done by the graphical user interface (GUI). The data are stored in an input file and can be expanded and used at any time for further analyses. The module GESIM BASIC analyses the geometry and strength acc. to DIN and NIEMANN as well as the tolerances and inspection data acc. to DIN. It generates plots of toothings, meshes and tools. The module GESIM FATIUGE calculates the damage, the fatigue life, the equivalent loadings and the torque – time curves for root and flank of cylinder gears under load spectra. GESIM POWER analyses the power flow through transmission, i. e. it calculates the speeds and torques on each element for every gear (speed), the bearing rating life considering the bearing and shaft deflections and toothing modifications. GESIM CAD generates a drawing of the finished part and the blank and GESIM NC generates the manufacturing program.

2.2 Interface GESIM - ADAMS

The GESIM ADAMS Interface generates virtual prototypes of transmissions for ADAMS. The interface extracts the data for each shaft, gear and bearing from the GESIM files. The resulting ADAMS models can be used for dynamic simulations of transmissions or drivelines.

Fig. 2: GESIM ADAMS user interface

2.2.1 Description of the Interface

The GESIM ADAMS Interface is a C++ program. It provides a graphical user interface, to enter the data by Windows style dialog boxes, fig. 2.

First the user selects either single gears (speeds) or all of them to create the ADAMS models for. In a tractor transmission you may have up to 48 gears (speeds), in some cases even more. For each selected gear (speed) there is an own CMD – File with only those gears that are power transferring connected by fixed joints to the shafts. The other gears are connected by revolute joints with the shafts.

Then the user specifies some information about the representation of shafts, bearings and gear pairs in ADAMS. Some of these notepages are shown in fig. 2.

It is also possible to view and edit the generated command files in an editor, which can be chosen by the user in the general settings, directly from within the GESIM ADAMS program.

GESIM ADAMS informs the user about the currently performed actions and about the generated files in the information window. Furthermore it displays the number of gears, shafts and bearings it has found in the GESIM input file.

The user can specify default directories for the input GESIM files and the output ADAMS command files.

2.2.2 Modeling of Transmission Elements

The command files generated by GESIM ADAMS represent virtual prototypes as 3D models of the driveline elements. They can directly be used for natural frequency analysis, vibration analysis or for investigations of deflection of shafts under dynamic loads. For driveline simulations the gears are represented by spring – damper elements, fig 3. The analyses can be done for spur and helical gears and in
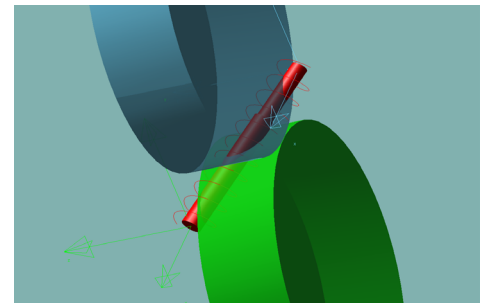
Fig. 3: Gear mesh in ADAMS

both driving directions – drive and coast side. Two spring – damper elements are generated for each mesh as there are two lines of contact. The actual one is depending on the direction of the torque. The forces are applied at the base circle and in case of helical gears out of the normal plane to the axis through the rolling point.
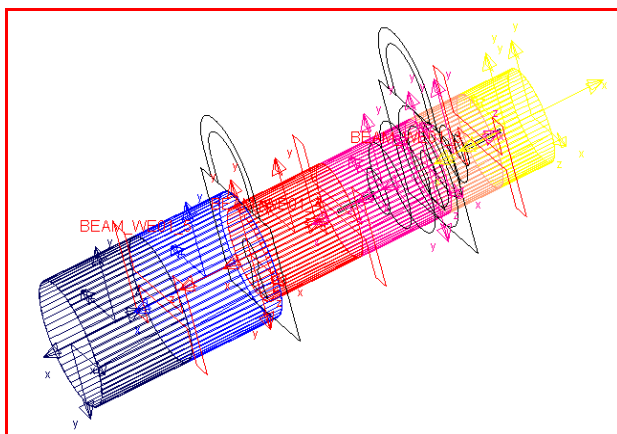
Fig. 4: Shaft model in ADAMS

The resulting ADAMS model includes data of masses, moments of inertia and geometry. The flexible shafts are modelled by Timoshenko or Bernoulli Beams. The shafts are splitted into shaft sections, where each section is again divided into two subcylinders. The BEAMS are built between two subcylinders and the shaft sections are connected by FIXED JOINTS, fig. 4. Fixed housing bearings are set up by SPHERICAL JOINTS, floating housing bearings by INLINE JOINTS, fixed shaft-shaft bearings by SPHERICAL JOINTS and floating shaft-shaft bearing by INLINE JOINTS.
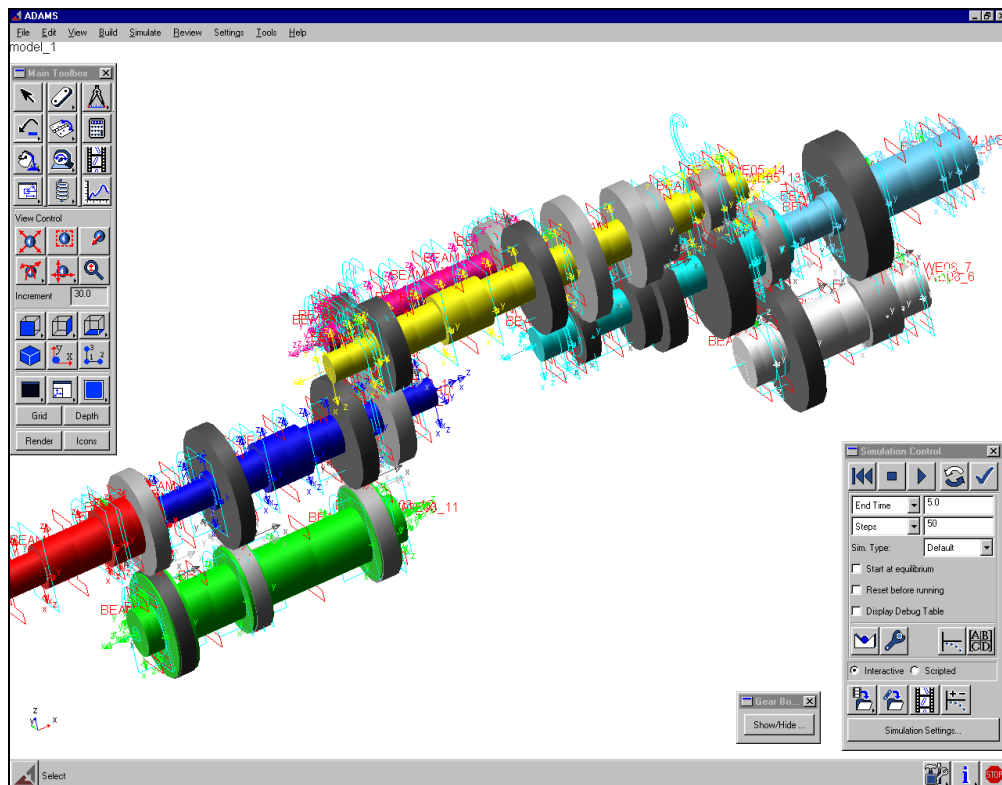

Fig. 5: Generated model of tractor transmission

Fig. 5 shows the model of a tractor transmission with 48 gears (speeds), 24 forward and 24 reverse. The high number of gears is achieved by multiplying the gears (speeds) of several groups: 3 (power shift gears) x 4 (main gears) x 2 (high – low) x 2 (forward – reverse). This is what ADAMS reads from the CMD file generated by GESIM ADAMS (only the icons are not displayed by default).

2.2.3 Parameterization

To increase the flexibility of the ADAMS model the main parameters of the gear meshes are set by design variables and subsequently by formulas within the model. Only those parameters that have influence on the driveline dynamics and that can be changed on the physical parts with reasonable effort are parameterized: the number of teeth of both gears, the helix angle, the normal pressure angle and the normal module.

3 GEAR MODULE

A gear stage in a transmission consists of a gear pair with the mesh, two shafts and four bearings, in the simplest configuration.

3.1 Gear Mesh

A gear mesh is a vibration exciter by several ways:

Fig. 6: Series and long addendum toothing

One is that the friction force changes its direction in the rolling point. Another excitation source are the toothing deviations that lead to non-optimal contact conditions. The varying stiffness of the toothing along the line of contact is usually the most important one. Even if the toothing was geometrically exact this excitation source would still be there.

There are several ways to improve the noise behaviour of gear meshes. One of them is the use of long addendum

Fig. 7: Tooth deformation comparison

toothings. One application where it was used with great success is described in /5/.

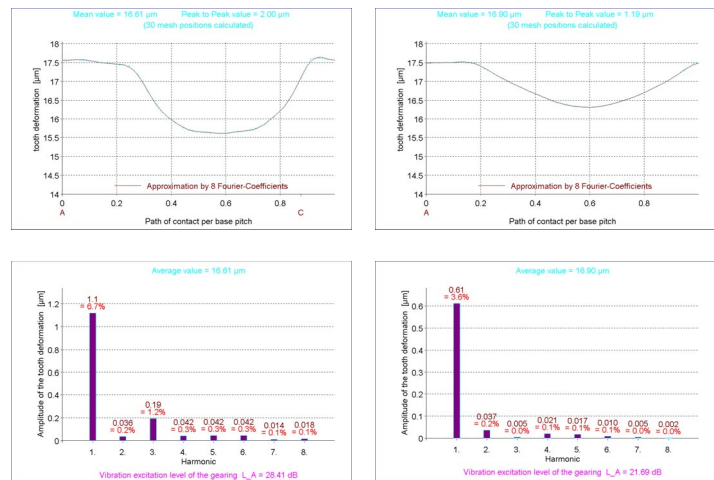Figure 6 shows the two toothing variants. The tooth deformation (calculated with /10/) along the line of contact at a constant torqueof the two variants is shown in figure 7. It is approximately reciprocally proportional to the stiffness. We can see that the long addendum toothing has a smoother characteristic and that its noise excitation level LA is just 21,7 dB instead of 28,4 dB. Especially the excitation of the first harmonic is reduced almost to half.

3.2 Roller Bearing Stiffness

In transmissions and gear boxes roller bearings are used.

Roller bearings have nonlinear stiffness characteristics. The forces and moments are dependent on the deflection and also on the clearance of the unloaded bearing. Fig. 8 shows an example. The curves belong to different clearances.
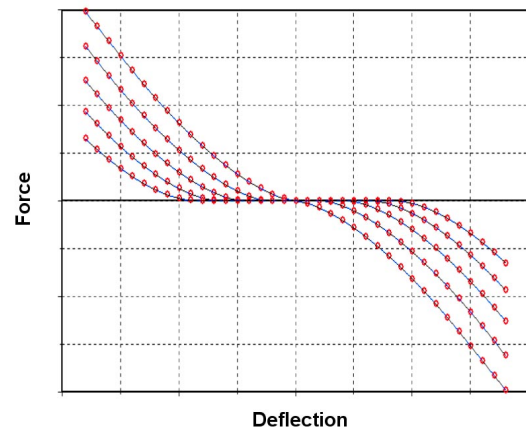

Fig. 8: Bearing stiffness characteristics

3.3 Mechanical Model

The essential elements of the gear mesh model are shown in figure 9. The model contains the mesh of a helical gear pair with its non linear stiffness characteristics and its damping, the masses and moments of inertia of the gears and shafts, the stiffness of the shafts as well as the stiffness of the bearings and the housing.
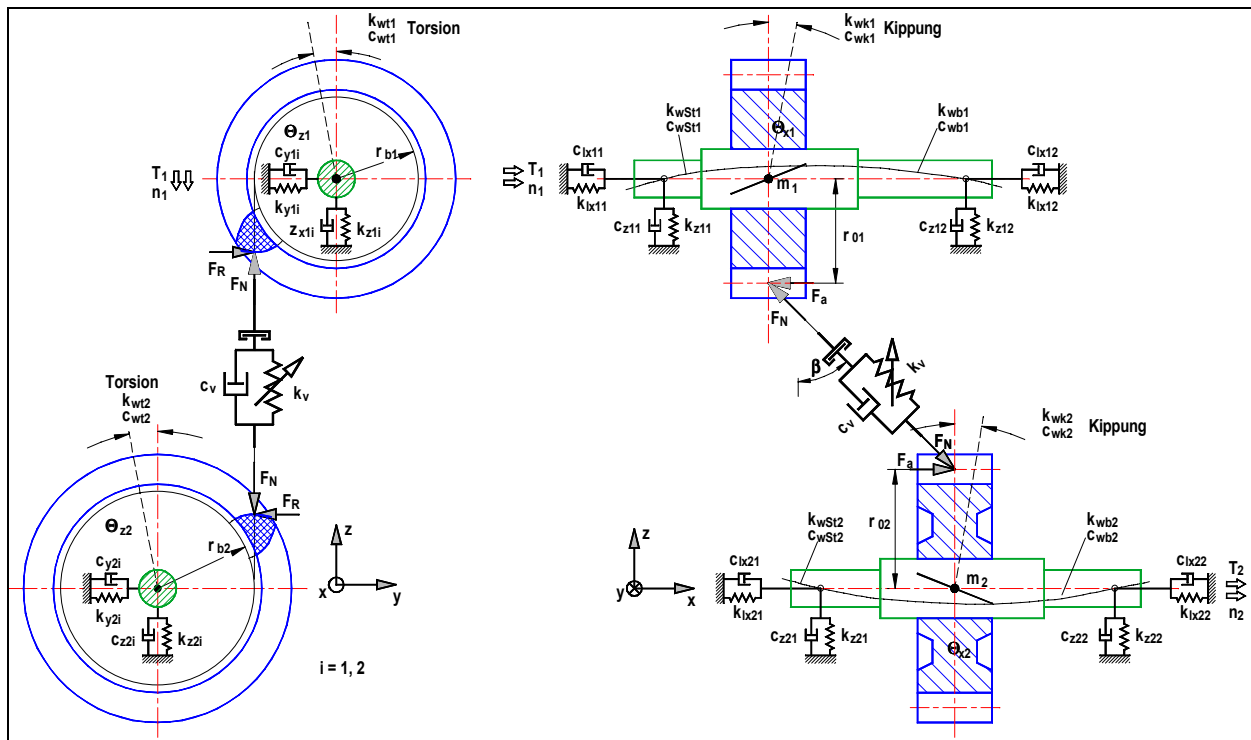

Fig. 9: Mechanic model of a gear pair

Fig. 9 is a simplified representation of the model used. Not shown are the torsional springs between the gears and the shafts, the torsional springs representing the bearing moments and the stiffnesses at the transmission input and output. Each bearing consists of two components: the nonlinear inner characteristic of the baring itself and the linear characteristic of the housing.

The bearing model is explained using fig 10. It shows only one DOF out of the six that there are.

The bearing position in the housing deflects under load. The bearing, strictly speaking the inner contour of the inner ring deflects relatively to the outer contour of the outer ring. Both together give the total deflection at the bearing position.
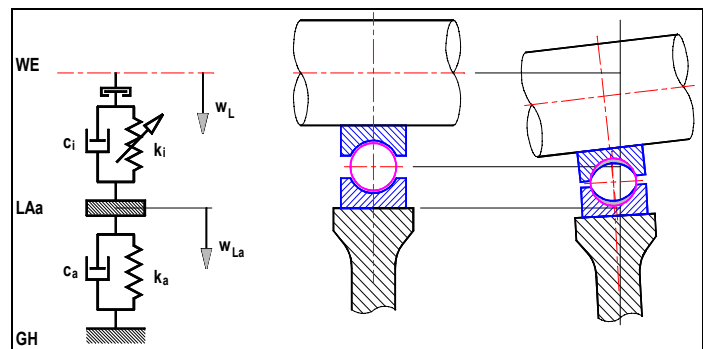

Fig. 10: Bearing model (only one DOF shown)

3.4 ADAMS Model

Fig. 11 shows the main parts of the model in ADAMS. The model is connected by a propeller shaft (not displayed) to a drive by a motion. At the output (also not displayed) there is another propeller shaft to take out the torque. In a complete transmission the connections have to be modeled according to the actual driveline.
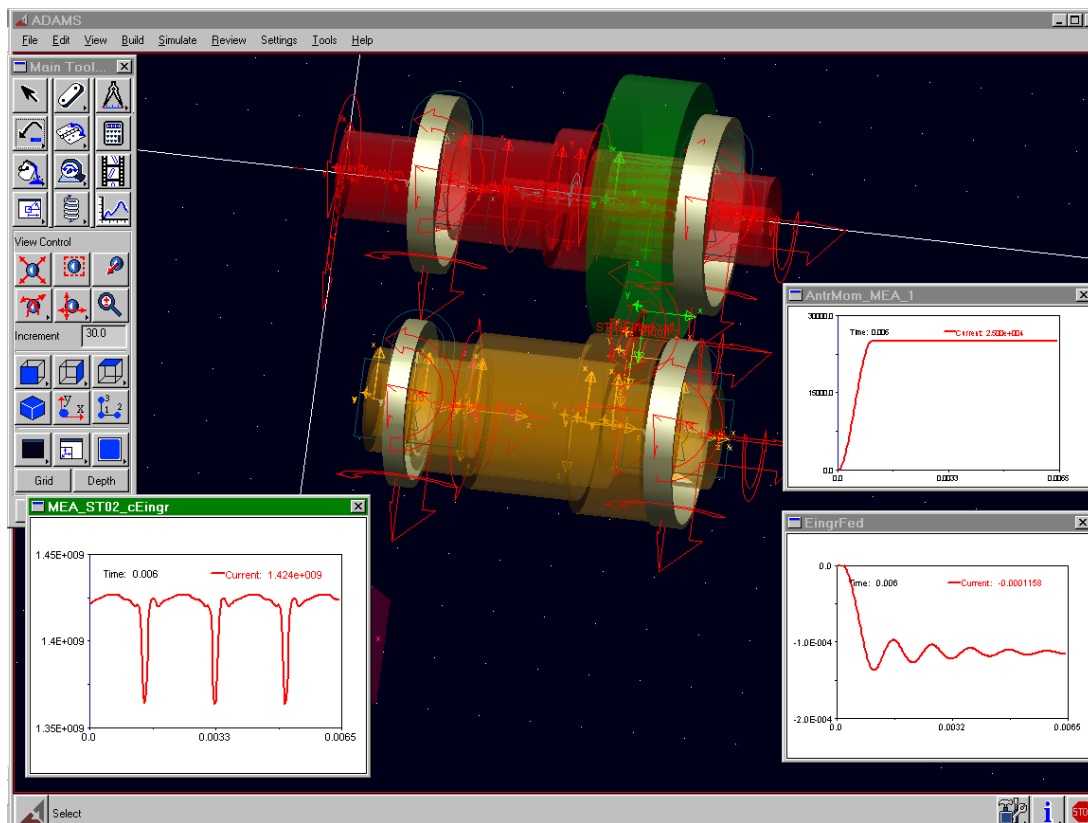

Fig. 11: ADAMS model of a gear pair

To be able to consider the characteristics of the varying tooth stiffness along the line of contact it is necessary to use GFORCE elements. There are no closed formulas to calculate the forces. Therefore user defined functions have to be applied. This ends up in using the GFOSUB routine in a Fortran subroutine. This subroutine calculates the forces belonging to the actual deflection. The deflection is determined by calling the SYSARY subroutine. The forces are passed back to ADAMS.

Furthermore the subroutine has to read the data for the toothing and the bearing. For speed reasons this is done only at the first call. Then the values are kept in the memory. During a simulation it is not necessary to read the input file again.

All the bearings and the gear mesh call GFOSUB. Within the subroutine first it is necessary to determine who is the caller. Then it branches to the corresponding read section (only at the first call) or to the corresponding analysis section.

The bearings are modeled by GFORCE elements too. These elements describe the complete support of the shaft by the bearing and the housing. First there is the bearing itself, means the area from the inner surface of the inner ring to the outer surface of the outer ring. There all the nonlinearities and the clearances are considered. Then there is the flexibility of the housing at the bearing.

Fig. 12: ADAMS model structure
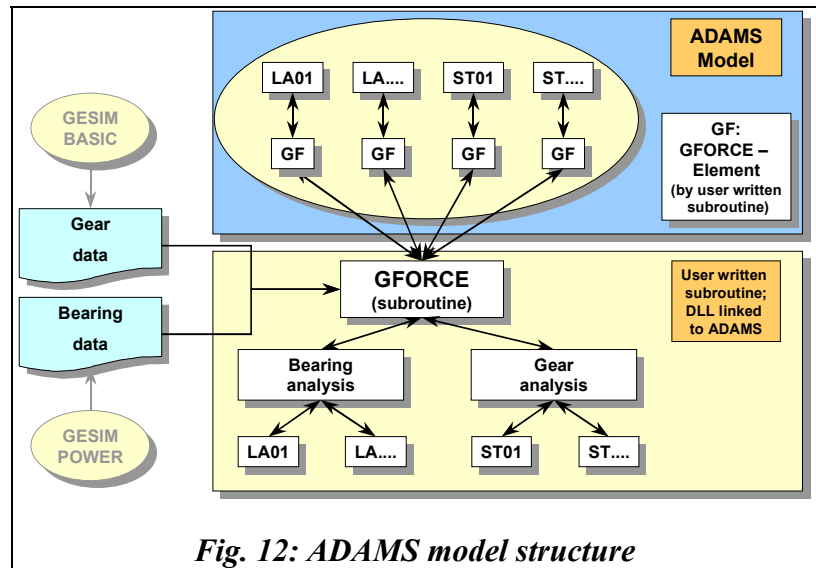
3.5 Modelling Aspects

One characteristic of the gear mesh is that the force application point changes on the part. The acting point is quite fix in space (it moves just a little bit depending on the deflection of the gears, shafts and bearings), but it moves relative to the part. This problem is solved by introducing dummy parts and putting a motion on them to keep them at the proper position. The motion of these dummy parts is dependent on the deflection of both gears and also on the turn angles.

In the current model the bearing support by the housing is modeled by a linear stiffness and a damping. It is no principle problem to integrate flexible housings. This will be done in one of the next steps.

4 CONCLUSION

The Engineering Center Steyr has developed the interface GESIM ADAMS which creates ADAMS command files for dynamic analyses out of the GESIM input files.

In the first layout stage GESIM is used for the analysis of geometry, strength, fatigue and manufacturing data of the transmission elements.

Then the interface GESIM ADAMS creates virtual 3D-models of the transmission for dynamic analyses. The advantages are the connection of the dimensioning with dynamic simulations, the data have to be input only once as they are passed to ADAMS, avoiding of possible errors by avoiding repeated manual input and a standardization of designations in the ADAMS model.

For detailed vibration and noise analyses the very accurate gear model is in development. It considers the varying stiffness characteristics along the line of contact as well as the nonlinear bearing characteristics and the elasticities of shafts and housings.

REFERENCES

/1/ *Leitner, J., Aitzetmüller, H., Marzy, R.:*
Das mechanisch – hydrostatisch leistungsverzweigte, stufenlose Fahrzeuggetriebe S-MATIC. Anforderungen - Funktionsweise - Simulation - Praktischer Einsatz (Mechanic - Hydrostatic Power Split CVT S-MATIC for Vehicles. Requests – Function Principle – Simulation – Application). Tagung Antriebstechnik - Zahnradgetriebe. September 14th – 15th, 2000, Dresden, Deutschland.

/2/ *Leitner, J., Aitzetmüller, H., Eichlseder, W., Marzy, R.:*
Steyr S-MATIC - Continuously Variable Transmission for Vehicles. Layout, Function, Efficiency, Simulation and Test Results. 4th World Congress on Gearing and Power Transmission. March 16th – 18th, 1999, Paris, France.

/3/ *Leitner, J., Aitzetmüller, H., Marzy, R.:*
Planetentriebe im stufenlosen Fahrzeuggetriebe S-Matic. Auslegung, Wirkungsgrad, dynamische Simulation (Planetary Gears in the Steyr CVT S-Matic. Design, Efficiency, Dynamic Simulation). VDI Tagung Zahnradgetriebe '99. 10. – 11. 03. 1999, Wiesloch, Deutschland. VDI Bericht 1460.

/4/ *Leitner, J., Wieser:*
Dentature ottimizzate per ridurre il rumore. Organi di trasmissione. p. 92-101. Marzo 1997.

/5/ *Leitner, J., Wieser, A.:*
Cylindrical Toothings with Optimized Stiffness Characteristics for Noise Reduction. International Conference on Gears April 22-24, 1996, Dresden, Germany.

/6/ *Leitner, J., Raab, G.:*
Äquivalente Belastung linearer Kollektivabschnitte (Equivalent load of linear load spectrum sections). Konstruktion 46 (1994) 381-385. Springer - Verlag 1994

/7/ *Eichlseder, W., Leitner, J.:*
Geometry, stress and fatigue analysis of gear wheels. Integration CAE - CAD - CAM. 3eme Congres Mondial des Engrenages et des Transmissions. 12. 13. 14. Fevrier 1992, Paris.

/8/ *Eichlseder, W., Leitner, J.:*
Getriebeentwicklung - Integration von Berechnung, CAD und CAM (Transmission development – Integration of analysis, CAD and CAM). Konstruktion 43 (1991) 353-357. Springer - Verlag 1991

/9/ *Eichlseder, W., Kaltner, G., Leitner, J.:*
Gear Dimensioning - Integration Analysis - CAD - CAM. ISATA - 23rd International Symposium on Automotive Technology & Automation. Advanced Automotive Manufacturing. Hofburg, Vienna, Austria - 3rd - 7th December 1990

/10/ *Software LVR*
Program LVR Lastverteilungsrechnung (Load Distribution Analysis) V1.7 by TU Dresden, Dr. Börner

/11/ *GESIM User Manual*
User manual for GESIM BASIC, FATIGUE, POWER, ADAMS by Engineering Center Steyr