INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN
ICED 03 STOCKHOLM AUGUST 19-21, 2003

# MODULAR MULTIFUNCTIONAL DESIGN TOOL FOR SPRING UNITS

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## Abstract

Increasing international competition forces manufacturers of industrial goods to shorten the development time of new products. This shall be achieved through a continuously computer aided design process and parallel procedures. Virtual prototyping is needed for a detailed description of the physical behaviour of a product in an early phase of the developing process. It is furthermore intended to reduce the high effort of developing and testing physical sample models. Therefore, virtual product models have to be provided which allow interconnection between different CAx software. To allow the designer an efficient use of existing CAx methods, both methods and user interfaces have to be adapted to the needs of the designer. This article introduces a design tool for springy units that fulfils the discussed requirements. This design tool can serve as an example of multifunctional tools made for a continuously computer aided design process because it integrates FEA and MBS software into a CAD system.

*Keywords: computer aided design, feature based design, parametric modeling, product model, virtual prototyping*

## 1. Introduction

Designers have always used springs to solve various technical tasks. Spring applications can be found in almost every product. This is primarily because they have got the capability to store potential energy under relatively large elastic deformation and release it at an arbitrary point of time. Springs in interaction with other parts, so called spring assemblies, solve various tasks in every technical domain [1].

They can be found in applications of well known traditional macro technologies such as textile, arm, and automotive industry. In addition, they serve as energy storing devices, actuators, oscillators, dampers, or bearings as well as deformation bodies, or connectors in products of highly innovative branches like medical or information technology. Printers, hard disks, or cardiac pace makers are only few examples.

New application areas arise from miniaturisation. This was made possible by specially developed techiques of micro electronics and micro system technologies. Basically, springs are used in this context to solve the same tasks as they do in macro technological applications. Together with other mechanical parts and elements of different functional principles they are integrated to extremely small micro systems and can not longer be considered seperatedly. Pressure-, crash-, airbag-, pitch-, and gear sensors are typical examples.

During the last years, an increasing number of springs with complicated shapes have been applied. Their design is adapted specifically to the constructive environment as well as the fulfilment of several different tasks. More and more, the dynamic behaviour of the spring has also to be taken into consideration during the design process to fulfil the increasing requirements for springy units in terms of reliability, durability, and precision. Moreover, customers demand small springs with low weight and at the same time high tolerable load capacities.

The reduction of the developing process of new products is a general demand. This has time – critical consequences especially for springs. In practice, currently available calculation methods can not sufficiently fulfil this requirements.

In addition, economic and competitive reasons necessitate the simulation of more complex assemblies. Therefore, new grounds of spring design have to be broken. Commercial simulation tools which provide suitable calculation methods have to be adapted to the special needs of designers of springs and springy units.

To achieve this aim, research work was done within the scope of a program of emphasis of the German Research Association (DFG) which dealt with computer – aided calculation and design of products [2]. The aim of this research was the development of an extensible design tool for springy assemblies which can connect FEA and MBS software and provide parametric interfaces. This article introduces the concept and realization status of the discussed design tool, based on the problem at hand. An example illustrates the design approach.

# 2. Problem setting

Standard springs can be dimensioned with help of the well – known analytical calculation methods. However, those methods can hardly be applied to new spring types which differ from standard springs and micro technical springy units. In those cases and for the dynamic analysis which can be most important for the function of springs, FEA methods are useful.

Furthermore, MBS models are particularly suitable for the analysis of springs and spring assemblies. Several commercial simulation tools (e.g. ADAMS®, ALASKA®, SIMPACK®, or DADS®) are available for the dynamic analysis of a spring assembly as well as the spring in detail.

Until now, working with those complex and universal CAx tools requires time consuming training periods. In addition, the modeling effort for springs and spring asemblies is still high. Currently, this leads to the fact that even simple analyses are not carried out by design engineers but by simulation specialists. This unwanted task sharing often causes information loss and loss of time. It contradicts an efficient use of the FEA and MBS tools.

To improve the currently dissatisfactory situation the development of object – orientated program systems is essential. Those tools have to be adapted to the needs of the designer and must be accessible from his familiar CAD environment. Subsequent to an analysis, the export of results data back into the CAD system must be trouble – free. First results in this regard were achieved through the so called SPRINGPROCESSOR which was developed for the analysis of springs and spring assemblies within the scope of the research project [2] mentioned above [3][4][5].

Applying the SPRINGPROCESSOR and the CAD/FEA tool to numerous examples proved it's practicability for vibration and strength analyses of springs without noteworthy problems. Difficulties arose in connection with analyses of large movements, calculation of eigenfrequencies of connected springs, and coupling of springs together with surrounding parts. Knowledge of the static and dynamic behaviour of springy units in connection with surrounding parts under variable load and boundary conditions is necessary in an early stage of the development process (figure 1) [6]. The targeted complex mode-ling of connected springs must therefore be aim of future research.

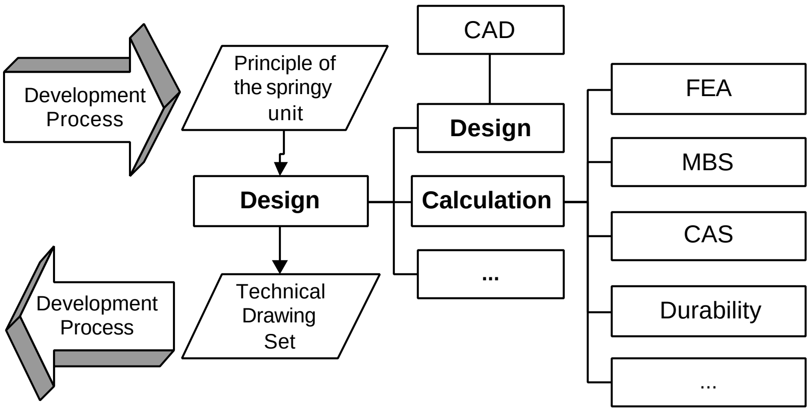



Figure 1. Placement in the development process.

Until now, applicable interfaces for bidirectional data exchange between simulation software and CAD tools are missing. This is the main difficulty for the discussed integration. The standard interfaces IGES, VDAFS, VDAIS, and DXF have problems in regard of bidirectional exchange or unsufficient capacity. Currently, even the product data model STEP® only provides the transfer of geometry data [7][8][9]. In addition, only data exchange between different CAD tools respectively the access to neutral data, e.g. in databases, was realized. Connectivities to simulation tools is essential and prescribed, but was not yet realized.

Concerning the exchange of parametric models, only implementation instructions exist. Until now, neither commercial implementation nor standardisation was realized. A first attempt to exchange software specific data of parametric models is known [10].

In this connection the known CAD tools are mentioned that include integrated FEA or MBS modules. The most important examples are CATIA® (GPS, GAS, EST), IDEAS® (MASTERSERIES), Pro/ ENGINEER® (PRO/ MECHNANICA), and AUTOCAD® (AUTOCAD Inventor). However, in most cases those modules do not provide sufficient capability for advanced calculations. In addition, they do not solve the problem of time consuming training periods and obligatory expertise for the designer.

The necessity of multiple model generation still remains, which demands valuable developing time. Programming parametric interfaces in advanced languanges [11] can currently be seen as the only possible and reasonable solution for the bidirectional exchange of geometric – physical data. However, this does not represent implementation of both systems but a connection through parameter exchange with following model generation in each program. This means, neither an internal shared data model (RIM) is used nor can geometric – physical data be exchanged through an interface. Thus, the effort of multiple model generation still remains.

## 3. Concept of the design tool

The concept of the discussed design tool is based on the coupling of  CAD software for the design of springy units and FEA, MBS, and CAS software for a continuous simulation of forces, stresses, and displacements. It supports the designer under his well-known CAD surface during the whole design process, starting with the early stage of developing principles and ending with the technical drawing set. The provided database with basic and expert knowledge (particularly for spring technology) also suits this purpose.

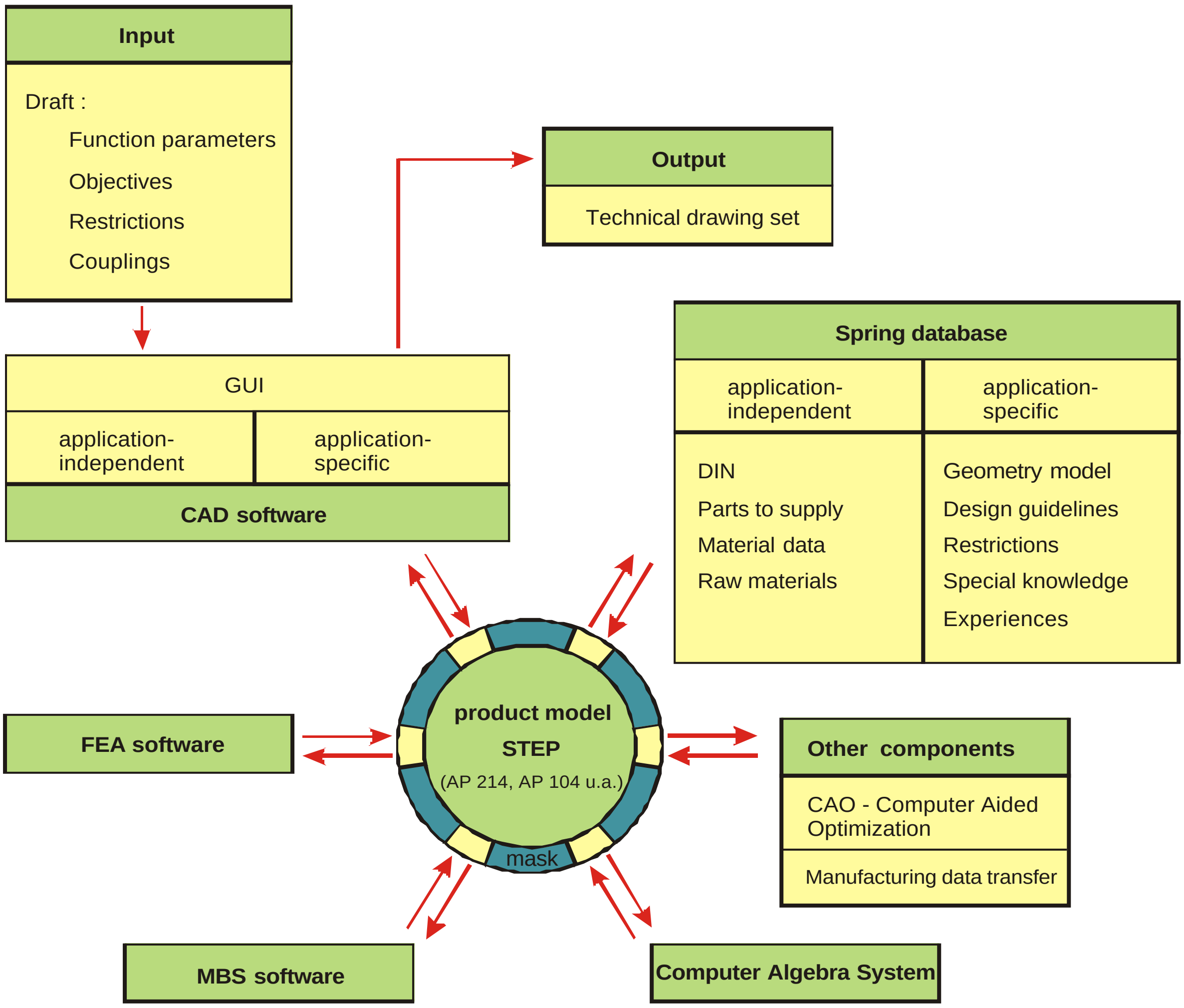



Figure 3. Design system for springy units (schematic).

The coupling of the different commercial CAx tools is based on a parametric product model which allows bidirectional exchange of geometric – physical product data. This product model shall avoid multiple model generation and is thus essential for the realization of the discussed concept. Through this approach an open and modular structure is achieved. In the future, this will allow an extension of the design tool, for example by implementing durability software.

Within the different CAx tools, various modeling approaches for springs and springy units are offered. The FE concept for example is devided into the analysis of standard springs and applications, analysis of standard springs within non – standard applications, and analysis of complicated springs. The MBS module offers four different approaches, depending on the analysis goal: characteristic approach, one – dimensional multi mass approach, three – dimensional multi mass approach, and combined approach [12].

For the designer's convenience a menu structure was provided and realized under the familiar CAD environment. The menu driven user interface is intended to facilitate the handling of the commercial simulation tools. For this purpose, in each module the model is normally generated automatically in the background. The menues are programmed using the individual programming languages of each simulation tool.

The development and availability of special features for the automatic generation of purposive calculation models including the obligatory data files is the condition for the realization of the discussed concept. In addition, a suitable product model has to be installed successfully. Those features must take into consideration the physical, geometric, and technologic properties of springs and available spring materials. They have to be implemented into the CAD environment. The discussed concept suggests the standard interface STEP® [8] as a basis for a standardized exchange of product model data.

# 4. Status and problems

With the exception of the STEP interface between the different CAx tools, the discussed design tool is basically already extensively realized. The applicable part of the relevant standard DIN ISO 10303 is currently limited to geometry and design data exchange and to data storage. It is not sufficient for the necessary exchange of physical and material data.

The development and implementation of STEP processors is comparatively progressive for CAD tools like Pro/ ENGINEER® which is applyed in the discussed concept. Realization is on the one hand based on the specific programming language EXPRESS® and on the other hand on standardisation of the complete product data concept in connection with the DIN standard mentioned above. However, in calculation tools STEP interfaces have yet been implemented only for the exchange of geometric data. This still makes it necessary to focus on the exchange of ‚simple' neutral C++ parameter files which are based on the STEP concept and contain all necessary information of the spring assembly (figure 3).

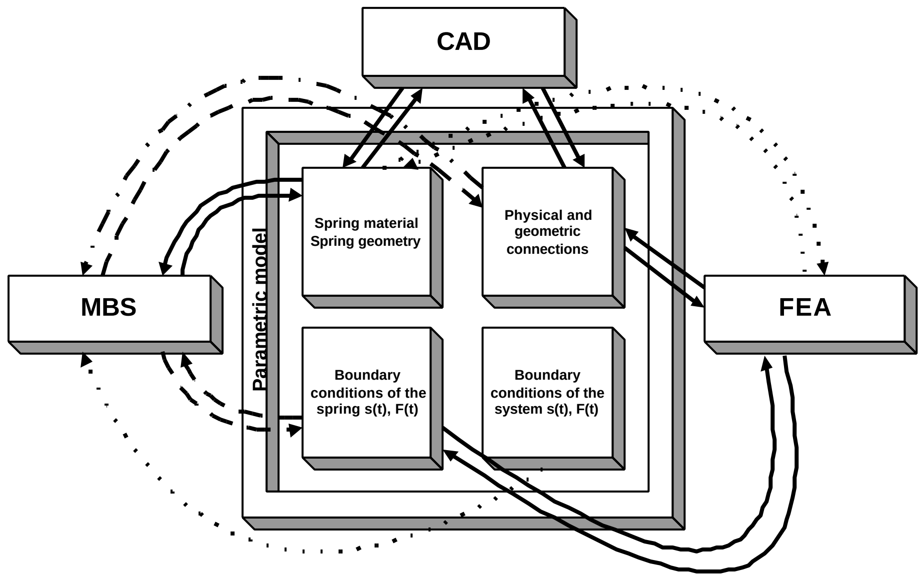



Figure 3. Data exchange.

Those parameter files can be actualized automatically within the coupled CAx tools. Each tool detects and uses it's specific part of the parameter file. The CAx software had to be adapted using C++ as well as the internal programming languages Pro/TOOLKIT™, APDL, and AVCL in order to realize a bidirectional parameter exchange.

The design tool can be controlled by an extended user interface of the CAD tool Pro/ ENGINEER®. However, both FEA and MBS tools ANSYS® and ADAMS® retain their specific user interfaces and full functionality. Additional functions for the simulation of springs and springy units are provided and contollable by graphical user interfaces within ANSYS® and ADAMS®. This makes it possible for the designer to use each tool seperately.

The SPRINGPROCESSOR mentioned above includes a pre- and postprocessor. It is written using the internal ANSYS® programming language APDL [3][4][5]. It is integrated into the environment of ANSYS® respectively Pro/ENGINEER® and can be accessed from both tools.

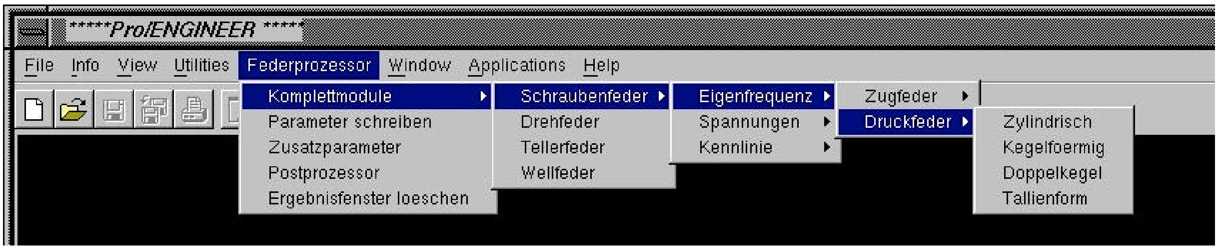



Figure 4. Adapted user interface of the CAD System Pro/ ENGINEER®.

The SPRINGPROCESSOR allows strength and vibration analyses for a multitude of spring types under variable load and boundary conditions. Thus, it provides parametric FEA modules for standard springs and models of shaped springs made of wire and strip material which allow a feature based design. The realized feature concept takes into consideration geometric, technologic, and function oriented properties (table 1). For practical and economic reasons the following three methods are offered:

- Modules for standard springs (shapes) under standard conditions of use;
- Modules for standard springs (shapes) under optional conditions of use;
- Feature-based modelling of shaped springs made of wire and strip material under optional conditions of use.

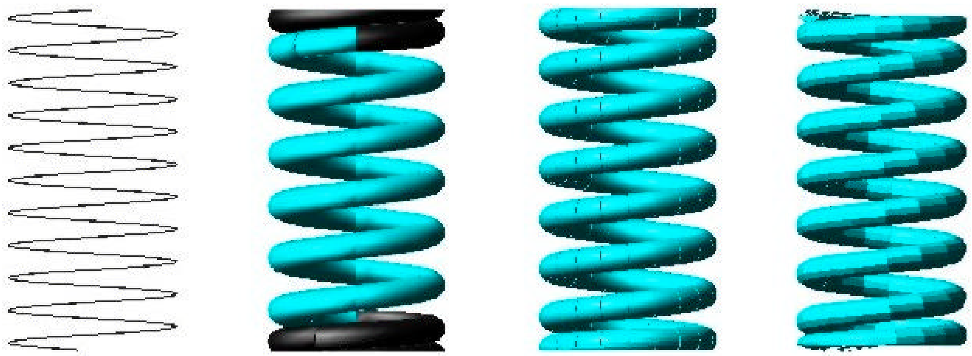
Table 1. Modeling Features for shaped springs.

| Geometry oriented elements | Function oriented elements | Function oriented properties |
|---|---|---|
| • Straight spring wire or spring tape elements with constant or variable cross section<br>Parameters:<br>- Length<br>- Cross section<br>• Bended spring wire or spring tape elements with constant or variable cross section<br>Parameters:<br>- Cross section<br>- Radius<br>- Included angle | • Contact elements<br>Parameters:<br>- Contact<br>- Stiffness<br>- Penetration depth<br>- Contact radius<br>- Contact distance<br>- Friction<br>- Status<br>• Spring-damper-elements<br>Parameters:<br>- Spring<br>- Stiffness<br>- Damping coefficient | • Material properties<br>• Initial and loading conditions, e.g.:<br>- Constraints<br>- Bearings<br>- Displacements<br>- Mass properties<br>• Results, e.g.:<br>- Spring characteristic<br>- Strength calculation<br>- Eigenfrequencies<br>- Mode shape<br>• Post processing |

The SPRINGPROCESSOR provides parametric modeling possibilities. Through menu driven user interfaces all required parameters, spring properties, and boundary conditions are defined, e.g. spring geometry, loading conditions, or analysis goal. After the definition phase, the FEA modules are called up for automatic batch mode model generation in the background. Subsequently, the FEA solver starts the calculation phase of the generated model. Finally, the results are provided automatically through coloured plots in a plot window of the FE module or through text file output.

The three modeling methods mentioned above can currently be accessed only from the ANSYS® environment. Standard spring shapes under standard conditions of use can be designed and analyzed with the discussed SPRINGPROCESSOR integrated into the Pro/ENGINEER® environment. Thus, numerous spring application cases can not yet be accessed from Pro/ENGINEER®. The Integration of the FEA modules for the other two methods is one topic of current research. In addition, the functionality will be extended to possible analyses of complete spring assemblies consisting of springs and surrounding parts like bolts, spring seats, plates, etc.

The current project realization status furthermore includes the integration and adaption of the MBS software ADAMS®. This is done based on the internal programming language AVPL. The MBS analysis provides any relevant displacement, velocity, acceleration, or force acting on any point of interest, depending on the chosen model (figure 5). Exact knowledge of these characteristics is especially essential for the description of springs under dynamic load, e.g. valve springs or suspension springs. In such cases the orientation of the resulting force and torque vectors is often arbitrary and not limited to the spring's main direction of action. In addition, the examination of impact loading that can enforce high frequency vibrations is of increasing interest. Knowledge of such load cases is essential for an exact prediction of the resulting stresses and strains and thus condition for durability studies.



a) b) c) d)

Figure 5. MBS models.
a) Characterisitc Approach; b) One Dimensional Appr. ; c) Three Dimensional Appr. ; d) Combined Appr.

At present, springs and spring assemblies can be modeled in ADAMS® using four model approaches (figure 5), whereof three are included in the commercial ADAMS® software. The following description of these model approaches shall be limited to helical springs. The so called characteristic approach (figure 5a) is relatively simple. The spring is described by it's characteristics and it's installed length. The spring force is proportional to the distance between two reference points on two different parts and to their relative velocity. Thus, the spring stiffness and a damping force can be modeled. Furthermore, preload and installed length can be varied. The characteristic approach is massless and does therefore not permit any examination of spring dynamics. It allows coarse design studies and is especially useful for the simulation of the interaction between the different parts of a springy assembly on the level of the Technical Principle.

The one dimensional multi mass approach (figure 5b) devides the spring into a number of separated masses in series connection. The masses are coupled by characteristic approaches as described above. With this approach the spring mass can be modeled. Beyond that, coil clash can be simulated through contact routines. This permits simple studies of the dynamic behaviour. However, the one dimensional approach is limited to the spring's direction of action. Thus, no effects in transverse direction can be simulated. This represents a coarse simplification because one dimensional impact loads will result in three dimensional reactions of the coiled spring wire. An important application area of the one dimensional approach is the examination of dynamic forces between springs and their surrounding parts in assemblies.

The three dimensional multi mass approach (figure 5c) consists of a series connection of bodies which inertial tensor is equivalent to the according wire section. The bodies are coupled by six dimensional force elements. This approach allows a detailed description of the spatial spring behaviour and thus provides advanced simulation possibilities. Even stresses can be calculated under usage of the reaction forces and torques between the different bodies. Stress simulation is yet primarily done by FEA software. According to the SPRINGPROCESSOR concept mentioned above, a menu prompted model generation permits parametric modeling.

Integration of the two main simulation methods FEA and MBS results in the so called combined approach (figure 5d). Flexible bodies generated by FEA tools are implemented into a MBS system. Within the MBS environment the boundary and loading conditions are defined. The combined system can subsequently be simulated. Although yet only linear flexible bodies can be exported the simulation of nonlinearities can be achieved through coupling of several linear bodies.

The database mentioned above (figure 6) provides the spring geometry. In connection with the CAD system it serves as a data pool for the spring design tool. While using this database, basic requirements of the spring to develop are requested through input masks. Subsequently, the number of possible solutions is limited by further specifications. Finally, an applicable spring is offered. The geometry parameters of this spring are provided for a following analysis. Futhermore, new solutions can be added to the database.

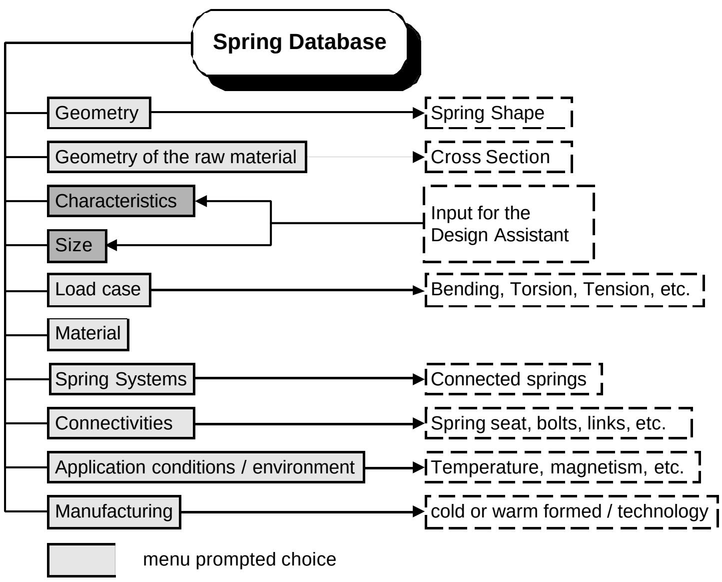



Figure 6. Contents of the spring database.

## 5. Example

The approach of applying the discussed design tool shall be explained below (figure 7). A cylindrical helical compression spring for dynamic load cases (valve spring) was chosen as an example. Normally the designer has got a CAD geometry model of a product at hand in which one or more springs must be integrated. This defines the installed length and characteristics of the spring. Thus, different purposive solutions from the database are displayed in menues.

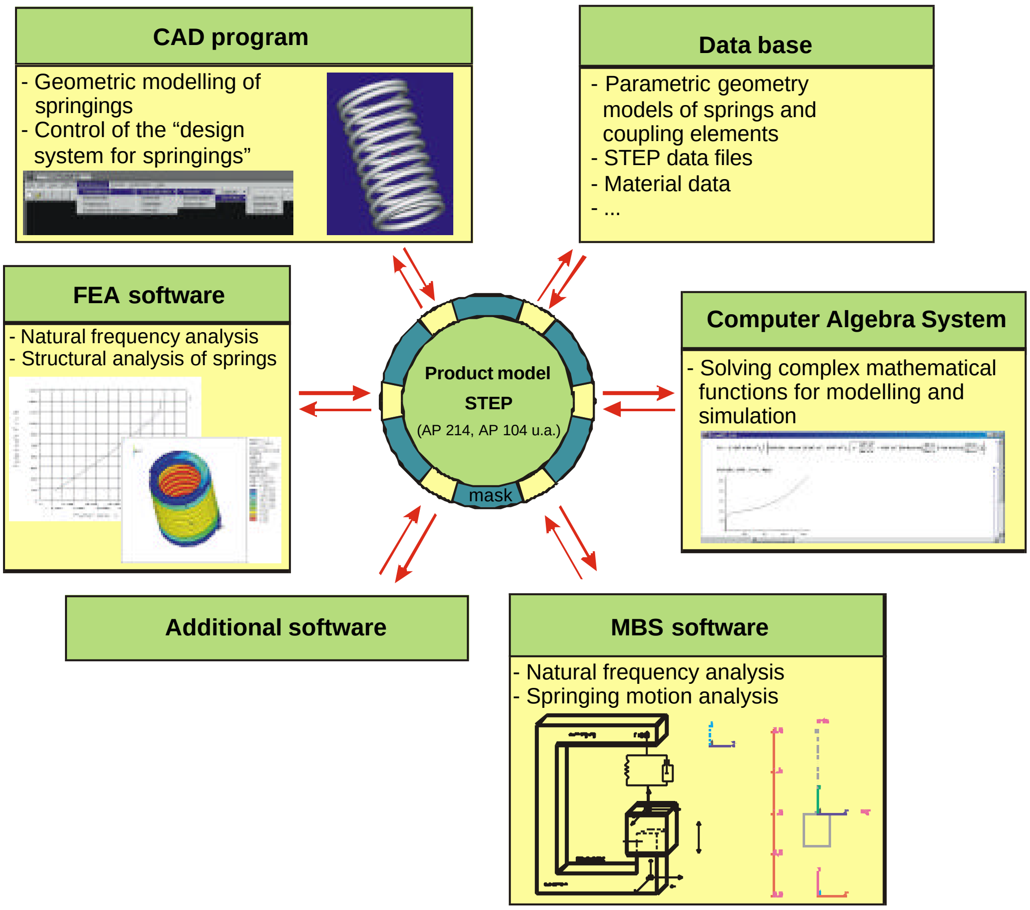



Figure 7. Simplified topology and example of use of the Spring Design System.

Subsequently, the designer has to range the spring geometry model of the chosen solution from the database into the design context. At this point, the spring parameters are allocated. A geometry and parameter file of the geometry and material data is then added to the database. This file serves as an input file for the different simulation tools. The next step is a static or dynamic analysis of the spring assembly. The simulation tools revert to the geometry and material data from the database. Further parameters like stiffness, damping, friction coefficients or boundary conditions are added to the model by menu prompts. After the simulation the model is saved as a parameter file and implemented into the CAD system.

## 6 Conclusions

This article introduces a design tool for springy units. This tool connects CAD software and commercial simulation and calculation tools. It allows a continuously computer aided design process for springs and springy units, starting with the early stage of developing principles and ending with the technical drawing set. Applying the design tool will allow a confidential and effective design process and a reduction of developing time. Furthermore, costs for the development and test of prototypes can be decreased by simulation. The design tool is extensible. The discussed approach can be applyed on other complex mechanical systems and machine elements. However, continuous application of the discussed approach is not yet possible in all cases. In addition, multiple model generation is still necessary. Solving the tasks in this connection is part of current research.

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