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The TVO Pipeline Analysis and Monitoring System

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ABSTRACT

To make fitness, safety and lifetime related assessments for class 1 nuclear piping, the amount of necessary input data is considerable. At the same time it is essential that the data is reliable, up-to-date, well traceable and easy to obtain. Often the information that is necessary for a specific project has to be collected in a very short time.

This paper outlines the contents of the database system, consisting of separate geometrical, material, loading, result and reference document databases, which is being developed by TVO and VTT. The system under development is intended to facilitate the analyses of class 1 piping and generation of most of the associated documentation.

KEYWORDS: database system, piping geometry, piping properties, piping materials, design loads, combination of load-cases, automation of stress and fatigue analyses, ageing management.

INTRODUCTION

In existing power plants, the number of people responsible for load, structural and vibration related projects might be very limited. This means that tasks related to obtaining starting points, performing an analysis and preparing documentation might be the responsibility of just one person. This person will be asked questions like:

* We want to make a change, what are the implications?
* We had an abnormal event, what are the implications?
* As part of the inspection planning we want to make a risk assessment, where do we get the starting points?
* We need up-to-date valve loading data to order a new valve, please supply?
* Will the existing piping system take the changed loads induced by the new valve?
* During the inspection we found a crack, can we run until next year's outage or even longer?

These are short questions with often not much longer answers, but a lot of work and an adequate and up-to-date documentation are necessary to give the answer. The latter may be a real problem for several reasons, such as:

* Load and strength analyses for different systems have been done over tens of years time span.
* These analyses, often made by different companies, have been performed and documented by different persons in different ways using different tools and have even been archived in different ways and at different locations.
* During the lifetime of the plant, there may have been a power uprate, major piping and equipment exchanges and modernisation projects. The documentation may not have always been fully updated.
* Changes performed in the plant may not affect the as build structures, but may affect future changes.

Some or all of the above reasons may have led to a difficult-to-use load and strength archive. Still there may be many situations where reliable and up-to-date information is needed fast. For this reason, the development of the pipeline and monitoring system was started

GENERAL INFORMATION WITH REGARD TO THE SYSTEM

The system presently under development is meant to contain all up-to-date information necessary to analyse and monitor piping systems for an existing and operating plant [7]. For a start only the TVO OL1 and OL2 units will be entered into the system. The system is basically an "as built" system and is not meant as a design tool although parameter studies will be possible. All data in the system will be accompanied by the necessary information with regard to its reference document, dates, version and validity. In case the necessary historical data is entered in the database, it will be possible to generate models for every as-build situation that has existed under the history of the plant. This will be done utilising the actual construction date. It will also be possible to keep an "as-designed/standard" version and an "as-built/measured" version. The latter could for instance contain updated support information that has been acquired through vibration measurements and modal correlation [3]. Other versions could be kept as well. It is clear that this would require very sophisticated bookkeeping and the development of this part of the program will not be started before the more "technical" side has been developed much further.

In case a load definition is changed, the system will "know" that the subsequent strength analysis and the associated results are not valid anymore. It is very important that subsequent analysis, like fatigue and fracture analysis, uses up-to-date input. In that way, the remaining lifetime can be estimated and the need for actions determined. And with a growing importance of parameter studies and probabilistic analysis it is more and more important to have the input data to the analyses in a flexible and readily available digital format [9].

The system will be built up of separate and stand-alone databases and program modules. Thus, different parts can be used for their own purpose without the whole system having to be completed or in use. Commercially available programs will be used as much as possible (database development, piping analysis, FEM, CFD, etc.). For special purposes, customised programs will be developed (crack growth, event monitoring etc.).

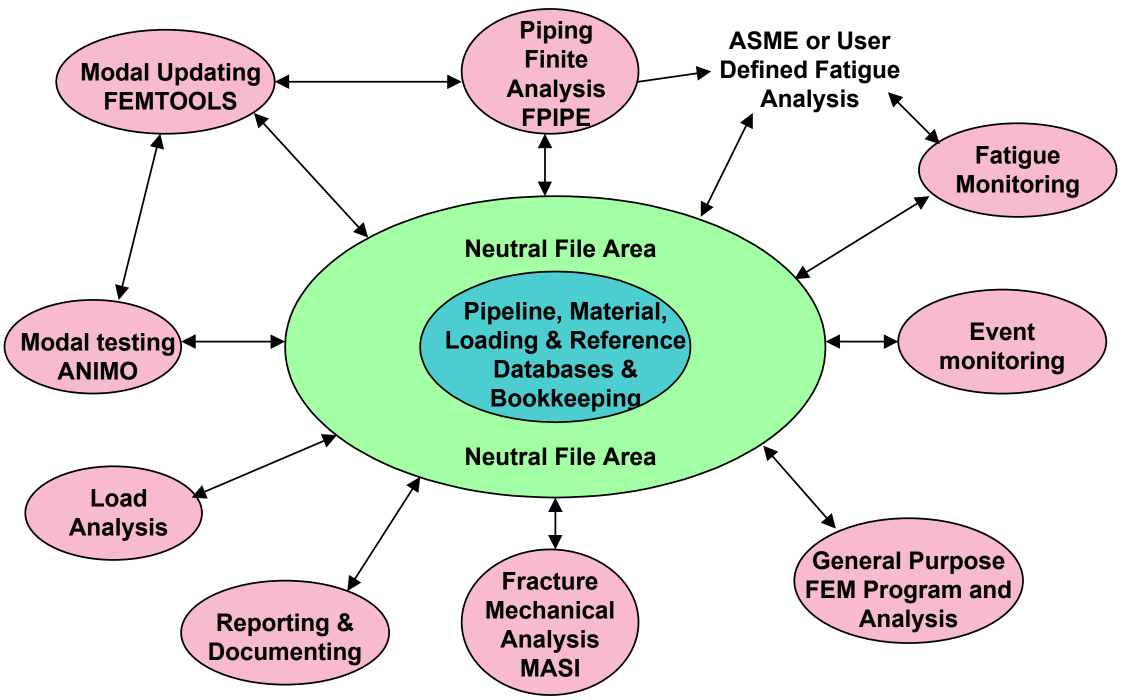

Fig. 1 Structure of the pipeline analysis and monitoring system

1. The core of the system consists of several interconnected databases and their user interfaces, and is called the database area. The contents of some of these databases are described in more detail in the next section. The different databases are edited with their own user interfaces that are designed to give visual information alongside alphanumerical. According to the present plans, control and navigation is, as far as possible, handled from this level. The database area is envisaged to contain the following databases developed using Microsoft® Access 2000 [8]:
   1.1. The piping database, containing information on or a reference to the geometry, material, contents, isolation, loading, boundary conditions, detected cracks etc.
   1.2. The material database, containing information with regard to the materials referred to in the piping database. These properties may be standard properties or measured ones.
   1.3. The loading database [1] containing information with regard to loads, loading combinations, ASME design and service level limits, design events and the history of occurred events.
   1.4. The result database containing all significant information with regard to the analysis results. Thus it is possible to perform subsequent analysis without first having to go through the stress analysis again.
   1.5. The report database containing the documentation that is related to the previous items. Input made to and documentation produced by the technical databases will refer to the relevant documents from this database.

For the moment items 1.1, 1.2, 1.3 and 1.5 have been developed to such an extent that 100% database/FEM-program data exchange testing can be performed. Actual plant data was entered to be able to do this testing on a realistic basis. Loading related data has not yet been entered.

2. At the outer border of the system are the application programs. This is called the application program area. As far as possible these programs shall only use data from the databases and run in batch mode. However, if necessary, data from external sources can be used as well. This may be the case when some new data for the database is obtained with special purpose programs. Basically, the application programs can be of two types:
   2.1. Commercial programs to perform structural, flow, thermal, fatigue, fracture mechanical and/or other analyses.
   2.2. Tailor made analysis modules to perform post processing of previously obtained results, event monitoring, fatigue monitoring, crack growth monitoring, definition of inspection intervals etc.

3. So-called "neutral" files are used as an interface between the databases and the application programs. As simple to use and straightforward neutral files containing only the minimum necessary amount of data do not yet exist another approach was chosen. In this system a neutral file is defined as the batch-input file controlling the flow of and supplying the necessary input data to the analysis module. This means that an interface module is necessary to write the necessary data from the database into the neutral file and in the right format. This interface module is designed in such a way that the user of the database package, i.e. the engineer responsible for the analysis, and not the programmer behind it defines the layout, format and contents of the neutral file. Thus only one interface module is necessary for all the possible application programs that are used through the database. A similar interface module will be made to extract significant data from the analysis program results back into the database.

ELEMENTS OF THE DATABASE SYSTEM

Piping database

The piping database consists of the piping geometry and all other information necessary to perform an analysis with one of the application programs. Therefore, it also contains information on for instance welds and equipment, boundary conditions and the materials of, in and around the piping. The organisation of piping geometry in the database is similar to the organisation of piping systems and related drawings at TVO. This organisation is as follows:

* At the first level, the system is found with the system identification number. Examples are the feed water system (system 312) and the relief system (system 314). Drawings at this level are called system isometrics.
* At the second level, the main parts of the system are found. The feed water system for instance is divided into parts called 312 BAA-1, 312 BAA-2, 312 BCA-1 and 312 BCA-2. There are no separate drawings at this level.
* At the third level, the piping geometry is divided into isometrics and associated part lists. At this level, the drawings have a part name followed by a sequential number, like 312 BCA-2-1, 312 BCA-2-2 and 312 BCA-2-3. This is the lowest and most detailed level of piping drawings available at TVO. Every isometric is entered into the system separately. Also the connectivity between the different isometrics is entered.

The above choices were made to make organisation of the database easy and recognisable for all possible users at TVO. Furthermore, possible future digital drawings will be organised in the same way and this will ease the data exchange between the systems.

Further division was made according to normal FEM convention. This means that the database contains nodes and elements with all sorts of associated properties. In this context "elements" refer to geometrical elements like straight piping parts or pipe bends and "nodes" to the points connecting these elements. This means that a new element starts whenever there is a change of any of the element properties. Separate nodes will also be appointed to welds or nodes that shall be analysed later on. Taking these rules into account is the work of the person entering data into the system and is very important when designing and building the database model.

However, the database model is not meant to be equal to the associated finite element model. It is meant to contain an as-build representation of the actual geometry inclusive main equipment, see also figure 2. This means that for instance additional nodes, necessary to perform a sound dynamic analysis will not be added in the database building stage but in the model building stage. To do this several approaches can be chosen:

1. Standard division of the elements in part with a maximum length that is defined by some rule.
2. Choose a finite element program that automatically refines the analysis until a sound solution is found. For this case the FPIPE program [4] could be enhanced with routines to automatically change the model and, by the use of an iterative solution method, come to an optimum solution.

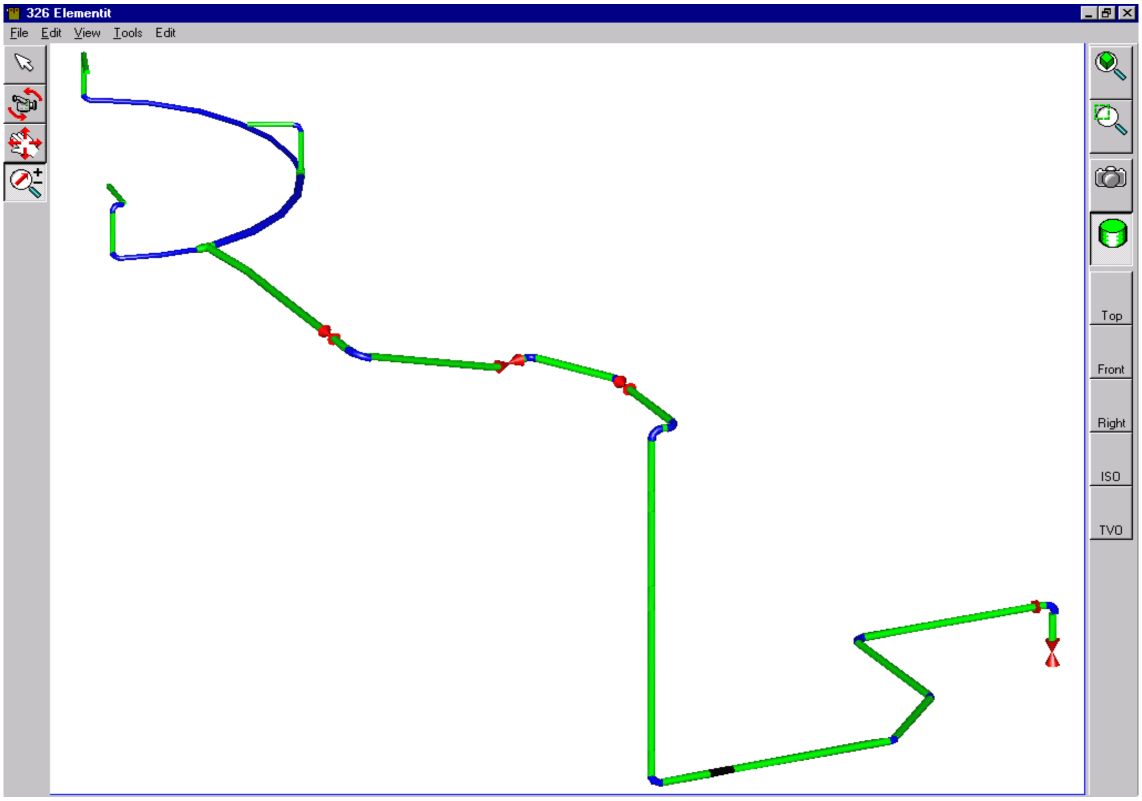

Fig. 2 Visualisation of piping using the piping database user interface

Examples of information associated with a node are:

* The node number, co-ordinates in the plant co-ordinate system and isometric number (document database ref.)
* Node element information like mass and associated stiffness and centre of gravity (simple valve case)
* Support information like stiffness, pipe whip restraint, stiffness matrix, gap or damping
* Reference to weld drawings inclusive weld (repair) information and dates
* Information as to what type of analysis shall be performed at the node (stress check, crack growth, fatigue etc.)

Examples of information associated with an element are:

* The element number, the nodes at the end of the elements and the isometric(s) to which the element belongs. As the isometrics can be found from the document database only a link to this database will be made.
* Cross sectional information like material designation, diameter and thickness of the pipe, the content designation and the isolation material designation. It should be noted that the designation of the material, contents and isolation is not more than a link to the material database. In this way the one of the most important rules of database design, namely “no data shall occur more than once in the database system”, is again fulfilled.
* The element type information like straight pipe, bend, T, reducer, expansion joint etc.
* Even very specific information like detected or postulated cracks can be entered into the database, see figure 3. In this way the system can also be used to perform bookkeeping of all the findings made during the inspections. Furthermore, it will be immediately available to perform subsequent analysis. During the, nowadays very short, outage, speed of analysis and adequate documentation is of great importance. As all the related starting points for such a subsequent analysis will be in the system the analysis should in fact not be more than a press-on-the-button.

The material database MATDBS

The material properties of the normally used materials at TVO are gathered in a database called MATDBS. At the moment the material database undergoes a complete revision. The material database is discussed in more details in paper O186 of this conference; title "Material Database" by Paul Smeekes, Jouni Alhainen, Aarne Lipponen and Heli Talja.

The loading database

The loads, combinations, events and everything else related to it will, as far as reasonable, be saved in a loading database. This database is described in more detail in [1]. The load database is designed to:

1. Contain and document the actually valid design load specification inclusive service limits
2. Act as an input database to perform stress, flexibility, fatigue and/or crack analyses
3. Perform book-keeping of the load-cases and -combinations that are valid at a time and contain the connection between old and new data
4. Give the structure for the result database where the significant results of analyses are stored.

Load-cases and -combinations are fully user configurable. In the present application either static or dynamic pressures, temperatures, weight, or forced displacements can be included as basic loads. These are included in the database or coupled as structured files in case of large data quantities. Presently, the database structure has been designed and is implemented. The items 1, part of item 2 and item 3 of the above list are implemented.

An example of the program interface display is shown in Figure 3. A transient load can be entered and visualised as shown. In addition, the source of the information is input as a link to the document database.

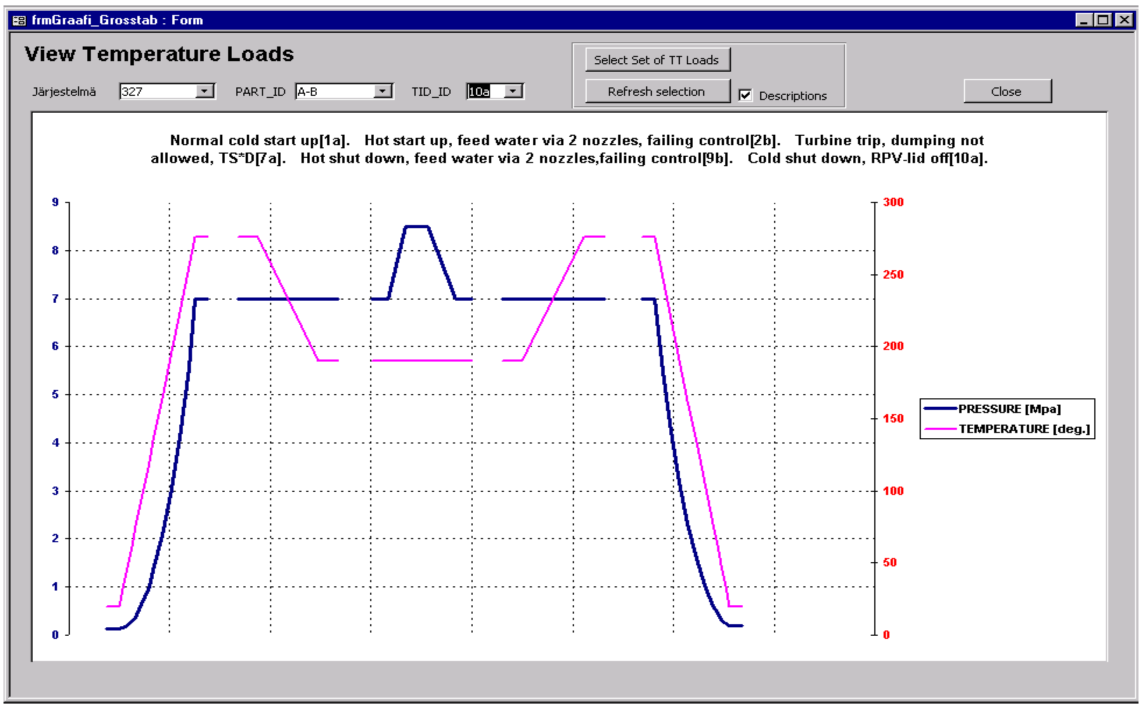

Fig. 3 Example of visualisation of the pressure-temperature load in the database

The document database

In order to find documents easily, a document database was developed. All documents that are related to any of the items within the TVO pipeline analysis and monitoring system will be gathered into this database. Once a document is part of the document database, it can be logically associated to any of the other databases. For instance, a load analysis report can be coupled to the load of the system (part) that it is related to. Also input data that was retrieved from an isometric can be coupled to the applicable revision of the isometric. In this way data in the database will always be accompanied by an exact trace to the data source. In case the database document is available in digital format even this file can be coupled to the document database and will thus be readily available from the PC. An extra option in the document database is that activities and deadlines may be associated to the documents and reports can be produced showing future activities and deadlines.

The document database contains information as to the validity of documents. Other modules of the database system can read this information and produce warnings or errors to tell that the source reference is not valid anymore.

After making the associations that are described before it is possible to automatically add information with regard to the data sources to the documentation that is produced by the system. For instance the crack growth analysis that is mentioned later on is performed as a batch analysis and could automatically generate a complete report with source references. Please, note that this is still future.

ANALYSES AND APPLICATION PROGRAMS

Organisation of data exchange

The data exchange between the databases and the application programs will be done via neutral files, and is described in more detail in section "General information with regard to the system" above.

Piping strength analysis

The piping strength analysis will be carried out with a commercially available piping analysis program and using the geometry, material properties and the loading as described in section "Elements of the database system". For the pilot phase of the project the program FPIPE [4] is chosen. In the future it shall be possible to use any piping analysis program. Compared to a basic piping calculation program, some of the following additional features may be useful:

* A very flexible loading definition enabling the loading to be directly defined by measured temperature data
* Automatic model improvement for a dynamic analysis.
* A transient analysis capability with a large number of time-steps for both analysis and output.
* Analysis with non-linear supports, gaps and friction and a dedicated bellow element, linear and/or non-linear.
* A capability to use integrated supporting structures or a matrix (from FEM-analysis) as boundary condition.
* A general linear elastic element with mass (valve, tank, etc.) shall be available. Replacement of an element by a matrix would be useful in case a more accurate finite element analysis has been performed to define this matrix.
* A capability to give shape factors for pipe-bends, T- and Y- joints, reducers and welds (from FEM-analysis).

Fatigue analysis

A fatigue analysis may be done according to the ASME, the materials' Wöhler diagram or any other method. The system contains a program that performs fatigue analysis according to the ASME III –standard [6] for class 1 piping. The input for this program shall be taken from the input data and results of many of the programs mentioned above. This analysis shall be performed for materials like ferritic and austenitic steel and INCONEL. Events causing loading shall be taken either from the design or historical event database. The strength analysis results for all locations analysed must be available to perform other analysis like for instance crack sensitivity analysis. In the design phase of the program the feed water system, system 312, together with the connected 327 and 321 systems will be used as a pilot system.

Fracture analysis

When performing fracture analysis, several crack growth mechanisms have to be considered, like crack growth due to cyclic mechanical loading or IGSCC. As these mechanisms are dependent upon the material and the environment these method(s) can be chosen automatically. These analyses may be performed using the simplified ASME method, the VTT developed MASI-PIPE program [5], or some other program using batch type input.

A conservative way to estimate the usage status of the piping may be made through the assumption of a postulated initial crack equal to maximum non-detectable crack at the least favourable location or then the worst detected crack. This crack shall, while including an appropriate safety factor, not grow to a critical crack before a planned crack or during lifetime. These cracks are assumed to grow from the last periodical check. The crack growth is estimated using the actual events at the station. Thus the worst possible crack growth can be predicted and necessary actions taken in due time.

Other developments

The following topics will be studied in the future:

* Flow induced loads, like water hammer or pump transients and pipe break loads
* Back coupling of pressure and temperature measurements. The inside temperature transients to be determined from the measured outside temperature transients.
* Bimetallic weld analysis
* Transient thermal- and flow analysis
* Transient and event monitoring based on events and/or measurements.
* Bookkeeping of inspection results.
* Analyses in conjunction with RIISI projects.

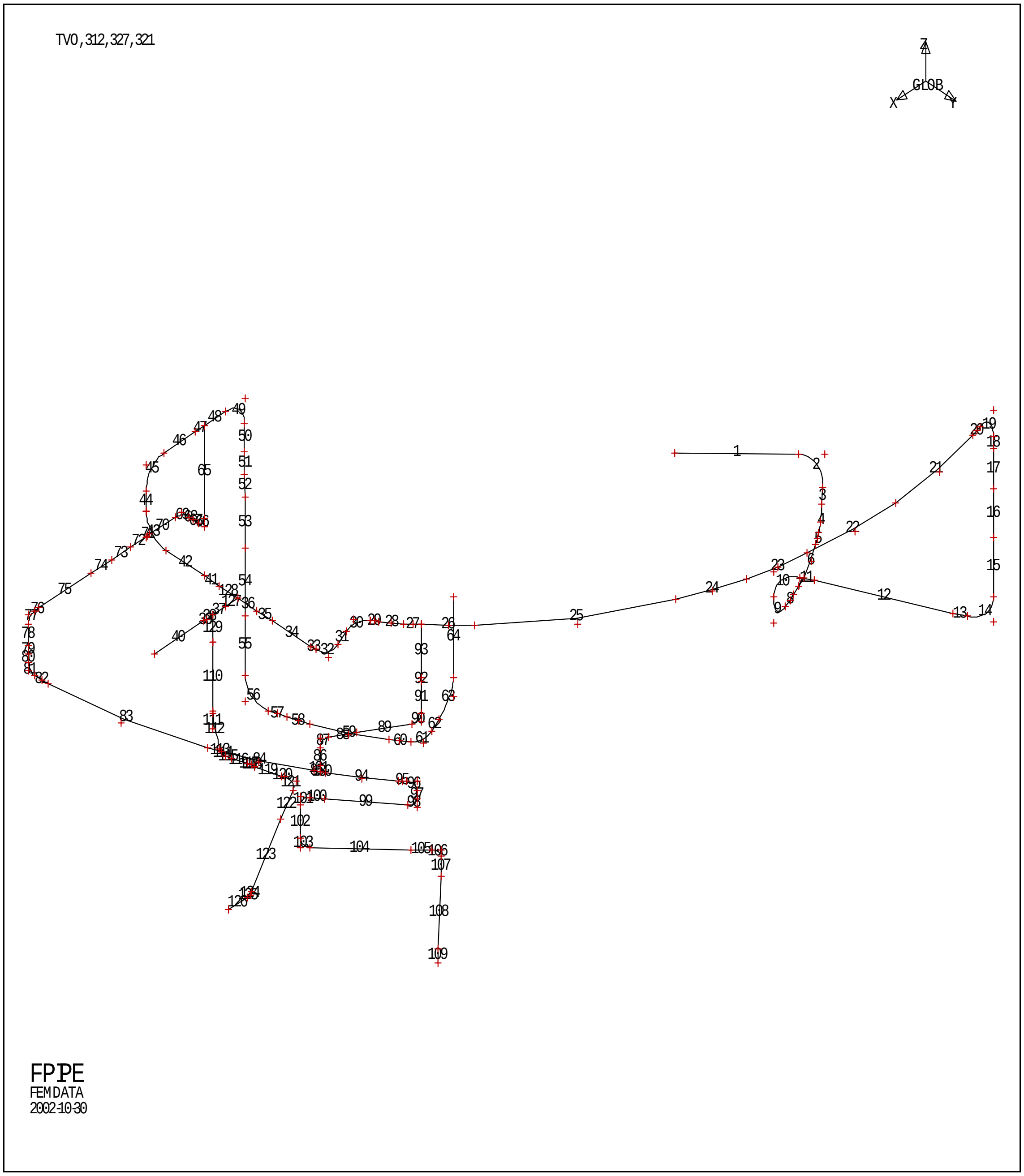

Fig. 4 Example of visualisation of the automatically generated piping mesh for the FPIPE programme

BOOKKEEPING AND VALIDATION

As the database will be quite complex, a good design and bookkeeping is very important. Records shall be kept for piping, equipment and other significant parts. The records shall contain such information as date of installation and possible exchange, as-build geometry and properties, welding, inspection and repair. Furthermore design loads and a complete load history shall be available from the database. Also the validity of the data shall be indicated. Thus analysis can be performed based on reliable and up-to-date information.

All information comprised in the database shall be accompanied by significant information related to date of installation or occurrence and reference documents. The date is important as for instance thermal cyclic loading that has occurred before a part was replaced shall be ignored with regard to the fatigue of the replaced part. Reference documents are important, as, in order to be significant, input data to analyses shall be traceable. Reports that are produced with help of the database shall contain references to the source of the information contained.

PROJECT ORGANISATION, TIME SCHEDULE AND PRESENTATION OF THE PROJECT

During the first years, TVO was the sole contributor to the project. During this period, the material database and the document database were developed, as was the base of the pipeline database. Up to this time, the interface was still alphanumerical. As test project, a pipeline geometry transfer was performed to a general purpose FEM-program. Since a few years, the project is a joint effort of TVO, VTT and FEMdata. In the project "Lifetime of pressure retaining components" [2] a practical toolbox consisting of computational and experimental tools is generated for effective condition monitoring of process piping and estimation of its remaining lifetime. In future, the use of this kind of tools will be much facilitated by connecting them to the database system. New features to the pipeline database are: the development of the visual interfaces to the database, the input and visualisation of cracks, the loading database, the second generation of the material database and the module that enables the user to generate a neutral input file to run an application program in batch mode. Application programs that have been coupled to the database are the finite element method (FEM) based piping analysis program FPIPE developed at FEMdata Oy and the MASI-PIPE crack analysis program that has been developed at VTT. As a part of the project, both application program systems are further extended and tailored to optimally fit the monitoring needs.

Developments for the near future are the result database and the bookkeeping features. Feasibility studies will be performed with regard to interfaces to one-dimensional pipe loading analysis programs, CFD-programs, modal analysis and update, general-purpose FEM programs and true neutral files.

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