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APPLICATIONS OF THE TVO PIPING AND COMPONENT ANALYSIS AND MONITORING SYSTEM (PAMS)

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ABSTRACT

To make fitness, safety and lifetime related assessments for piping and components, the amount of data to be managed is getting larger and larger. At the same time it is essential that the data is reliable, up-to-date, well traceable and easy and fast to obtain. At present the main focus is still on piping, but in the future components will be more and more developed.

This paper presents a piping and component database system, consisting of separate geometrical, material, loading, result and document databases as well as some current applications of the system. By means of a user configurable interface program the user can generate indata files, run application programs and define what data to write back into the result database. The data in the result database can subsequently be used in new input files to perform postprocessing on previous results, for instance fatigue analysis or RI-ISI (fatigue or crack-growth). The system is intended to facilitate the analyses of piping and components and generate well-documented appendices comprising significant parts of the input and output and the associated source references.

INTRODUCTION

The system is meant to contain all information necessary to perform most of the standard analyses and monitor piping systems and components for an existing and operating plant [7]. At present most of the piping inside the containment of the TVO OL1, OL2 and OL3 units are entered into the system. Later more will be added. The system was initially meant as an "as built" system, but is now also used in the documentation review of the OL3 plant that is under construction.

All data in the system will be accompanied by the necessary information with regard to its source reference, dates, version and validity. It will be possible to keep models for system configurations that have existed during the history of the plant or even an "as-designed/standard" version and an "as-built/measured" version. It is clear that this requires sophisticated bookkeeping. This part of the program will start after the more "technical" part.

In case a load definition is changed, a new load analysis and load summary report will be issued. These will make the old reports obsolete in the document database. The system will "know" that the subsequent strength analysis and the associated results are not valid anymore and issue warnings to the user. With a growing importance of parameter studies and probabilistic analysis it is important to have the analysis input data readily available [9].

The system will be built up of separate and stand-alone databases and program modules, the size of which were kept small while still maintaining a complete and logical entity. Thus different parts can be separately developed and used for their own purpose without the whole system having to be completed or in use. As the programming languages are developing very fast and modern tools shall be used as they give more possibilities and improve the performance, the next development was the independence of the development program language.

For the subsequent analyses commercially available programs are used as much as possible (database development, piping analysis, FEM, CFD, EN/PED related component analysis etc.). As the updates of these programs are handled by professional organizations adaptations to the latest developments will always be available. Only for very special purposes, customised software has been developed, like RI-ISI, crack growth analysis and documentation and event monitoring.

The programmers perform extensive testing of the developed modules. Most modules provide immediate feedback by data visualisation. For example thermal, pressure and other transient loadings are animated directly from the PAMS system.

The main part of the development was performed by TVO and its consultants. Other partners involved have been the Helsinki University of Technology, Technical Research Centre of Finland, students of the Rauma school of Engineering, Rostedt OY and FEMdata. As the system is developed and used by a small group, a unique approach was chosen. The main idea is that the system produces files and documentation that contain all references to associated source documentation thus enabling the user to efficiently check the indata. The PAMS-system itself only dumps information onto a structured file.

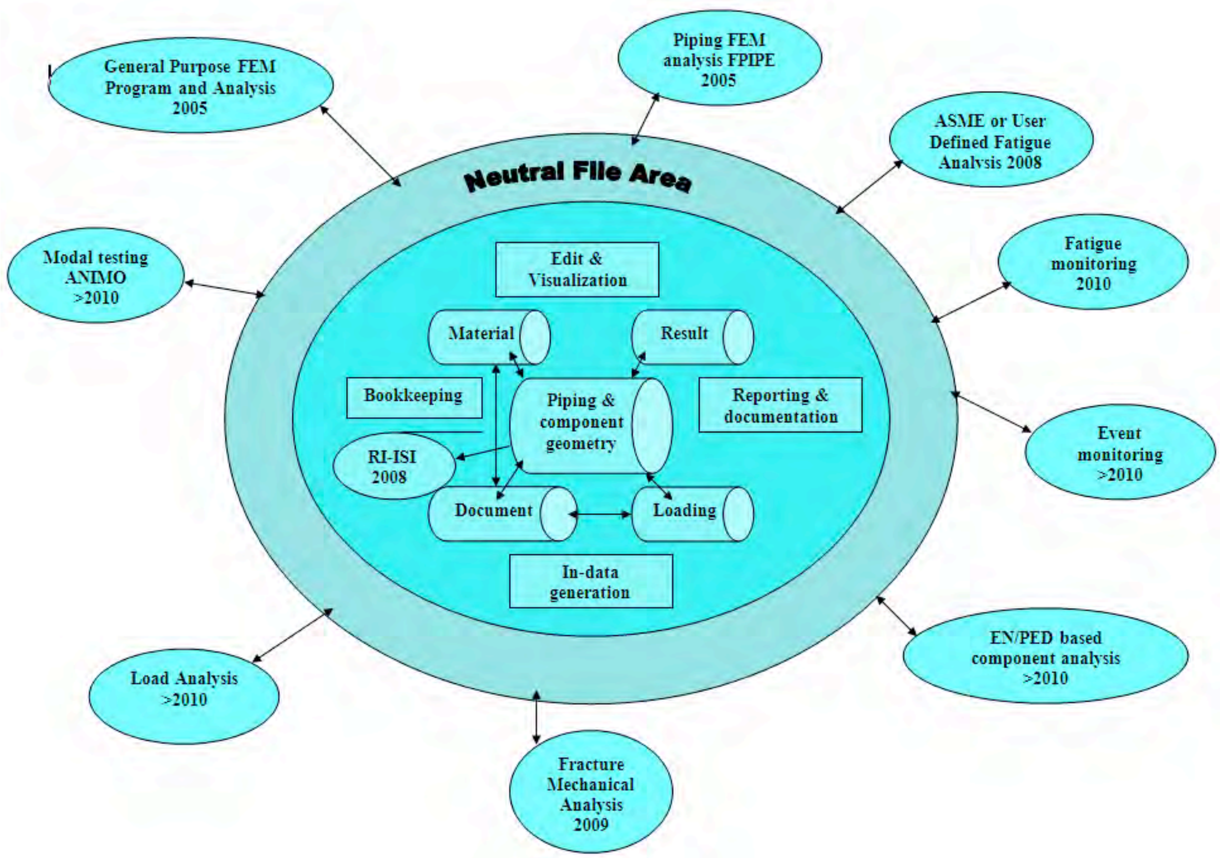


Fig. 1, structure of the pipeline and component analysis and monitoring system

The pipeline and component analysis and monitoring system consists of the following main parts:

1. The database area with several interconnected databases, see figure 1

The different databases are edited with their own user interface modules that are designed to give visual information alongside alphanumerical. Programs within the database area communicate directly with the databases, see figure 1. These are for instance the indata visualisation modules and the RI-ISI application.

The database area contains the following Microsoft® Access 2000 [8] databases:

1.1. The piping and component database, containing the geometry, material, contents, isolation, welds, loading, boundary conditions, detected cracks etc.
1.2. The material database, containing information with regard to the materials, sometimes extending to charge information like chemical composition.
1.3. The loading database [1] containing loads, loading combinations, design and service level limits, events, cycle quantities and measured histories of events that have occurred.
1.4. The result database containing the full analysis input and results for subsequent analysis as well as all help files and database tables.
1.5. The document database contains the documentation associated to the above items.

2. The external area with the application programs

Apart from some analysis control application programs get 100% of their indata from the databases and run in batch mode. Large result files (thermo-hydraulic analysis) will be stored as files only. Two programs types are:

2.1. Commercial programs for structural, flow, fatigue, fracture mechanical or other analyses.
2.2. Tailor made programs for post processing of previously obtained results, event monitoring, fatigue monitoring, crack growth monitoring, definition of inspection intervals etc.

3. The neutral file area for the communication between the databases and application programs.

The neutral file is the batch indata file according to the programs' user manual ("real" neutral files do not yet exist). Sophisticated user definable interface modules write data in the right format from the databases into the indata file and extracts data from the analysis program printout results back into the result database.

ELEMENTS OF THE DATABASE SYSTEM

Piping And Component Database

The organisation of the piping and component geometry in the database is similar to the organisation of the TVO drawings that are associated to the piping systems and components and is thus well recognisable to TVO users:

* Level 1, system with the system identification number. Drawings at this level are called system-isometrics.
* Level 2, the main parts of the system are found. There are no separate drawings at this level.
* Level 3, the isometric drawings and associated part lists, the lowest and most detailed level of piping drawings available at TVO. Geometry, material and welding related information is entered at this level and linked to the isometric drawing and other associated source references in the document database.

The database contains nodes (topology, boundary conditions etc.) and elements (piping, component parts etc.) with associated properties. When entering data this is visualised and can immediately be checked for soundness. The database model is looking like a finite element model but actually contains an as-build and/or as-designed representation of the geometry. Additional structures necessary to perform a sound dynamic analysis can de added to the model, see also figure 2. For the indata file the elements can be automatically divided in parts with a user definable maximum length.

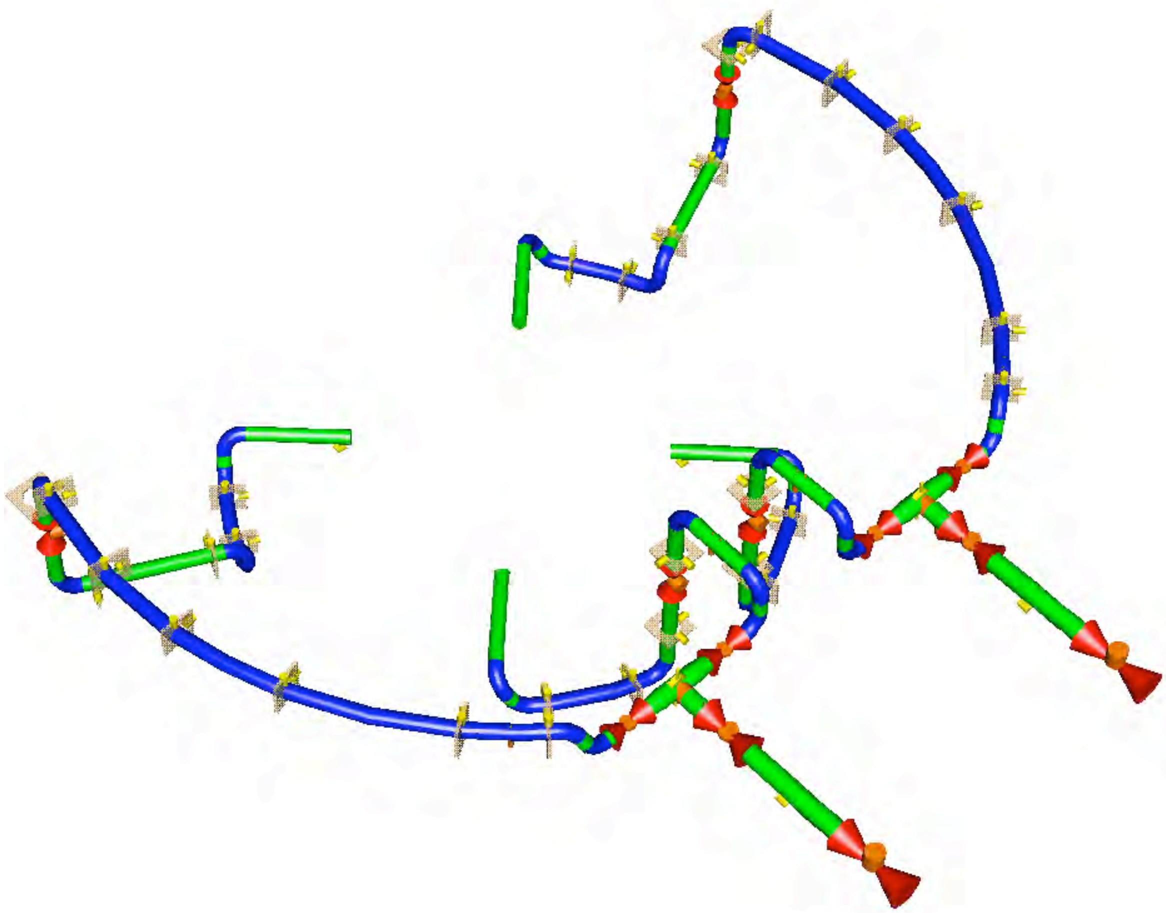


Fig. 2, visualisation of piping and supports with the piping database graphical user interface

The Material Database MATDBS

The material properties of the materials used at the TVO powerplant are gathered in the material database [11], see figure 3. This database contains both standard values from material standards and measured values from material certificates. For instance for the RI-ISI application it was necessary to assess the sensitivity to stress corrosion cracking and thus even the actual chemical composition was entered into the material database.

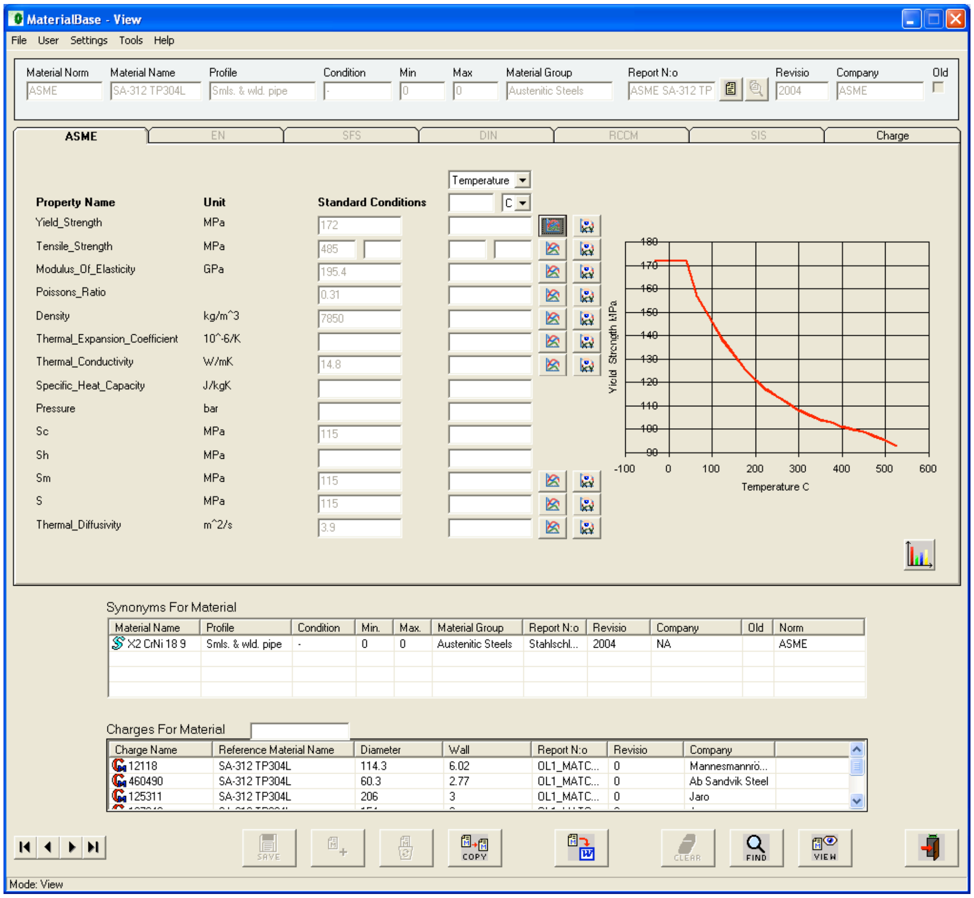


Fig. 3, visualisation of material input

The Loading Database

The loads, loading combinations, events and everything else related are saved in the loading database [1].

At present static or dynamic pressures, temperatures, weight, or forced displacements can be included as basic loads and linked to their source document, see figure 4. These are stored in the database or, in case of large data quantities, coupled as structured files. A transient load can be entered and simultaneously visualized as shown below.

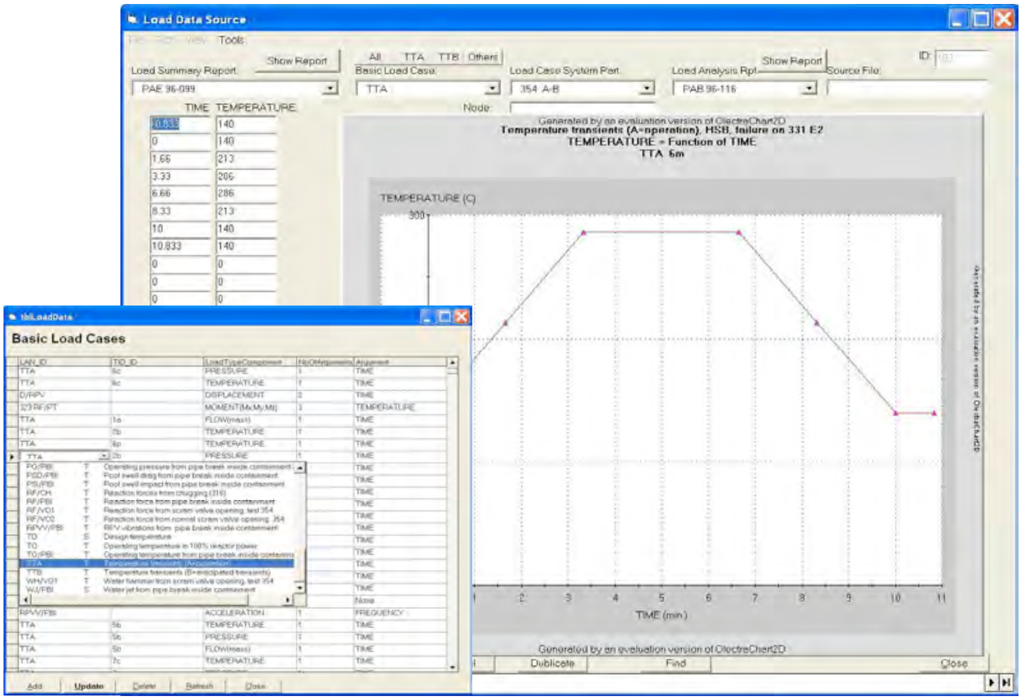


Fig. 4, example of visualization of a transient pressure-temperature load in the database

The Document Database

The document database, see figure 5, contains documents that are linked to information items within PAMS. For instance, a load analysis report is coupled a load, see figure 4 and material properties are coupled to their source reference, see figure 3. Due to the links it is possible to open the document. The document database even contains information as to the validity of documents. Other modules of the database system can use this information to produce warnings or errors.

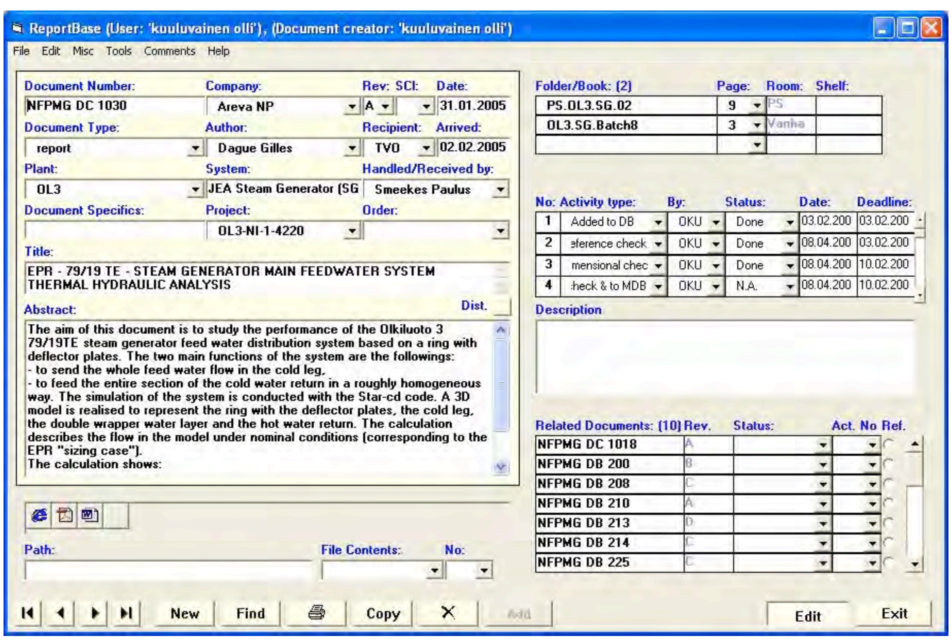


Fig. 5, example of visualization of a transient pressure-temperature load in the database

ANALYSES AND APPLICATION PROGRAMS

Piping Strength Analysis

The piping strength analysis is carried out with commercially available piping analysis programs. At present the Finnish program FPIPE [4] is in use, see figure 6.

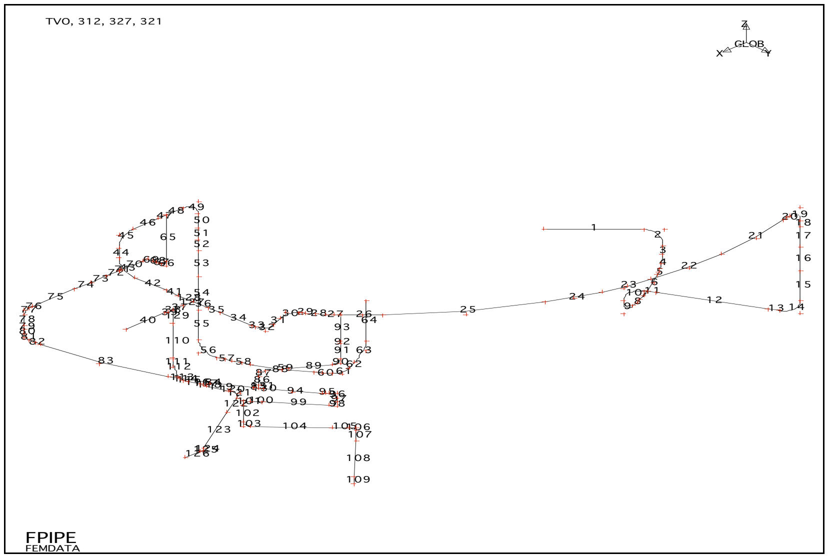


Fig. 6, wire-frame model of a piping model in FPIPE.

Basically it is possible to use any piping program using an alphanumerical batch input file. Analyses were also performed with ANSYS. When doing a dynamic analysis of the complete containment, RPV and class 1 piping inside the containment the database was used to generate the piping models inclusive piping supports, see figure 7.

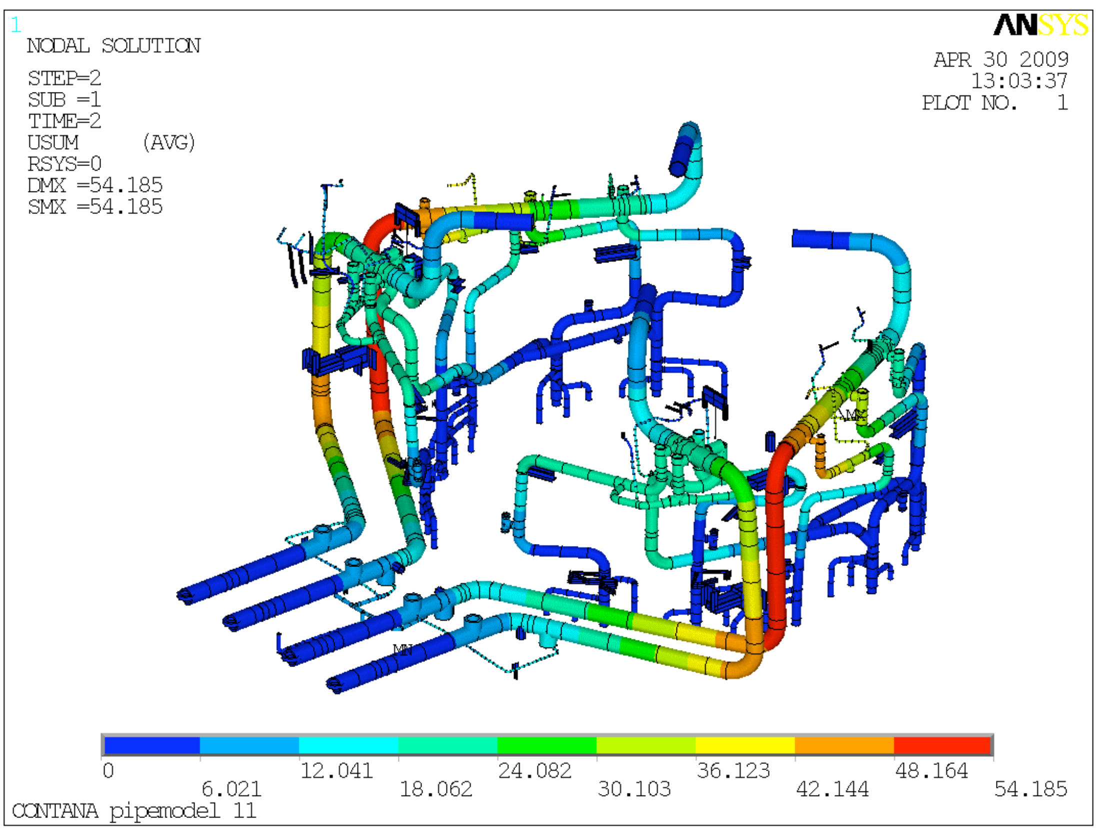


Fig. 7, Results for a PAMS piping model inclusive supports that was generated for ANSYS.

Fatigue Analysis

It may be necessary to perform a fatigue analysis according to the ASME, the materials' Wöhler diagram or any other method. FPIPE has a program module that performs fatigue analysis according to the ASME III –standard [6] for class 1 piping. This program module has been further developed to perform exact thermal transient analysis and automatic cycle induced fatigue usage analysis. Next the effect of LWR coolant environments on the fatigue life will be taken into account according to the procedure that is described in [12]. The input for this program will be taken from the input data and results of the programs mentioned above and will be 100% automatically extracted from the databases described earlier on. Events causing loading are taken either from the design or historical event database.

RI-ISI

Actually the first application of the PAMS system that was used to directly generate a complete official documentation was the RI-ISI-application according to the ASME - Boiler & Pressure Vessel Code, Section XI [14], appendix R, method B. This application was developed in 2007/2008, mainly applied in 2008 and the resulting documentation was approved by the Finnish Regulator STUK in early 2009. In figure 8 the segment division for the feedwater lines and the visualized risk class for one of the segments are shown. Apart from figures like the ones shown below the document consists of explanatory text and tables containing all significant information related to the system under consideration and obviously all the necessary intermediate and final results. The largest effort was to generate and enter the indata into the system.

The next step in the TVO RI-ISI development will be the introduction of probabilistic fracture mechanics to determine failure probabilities and risks.

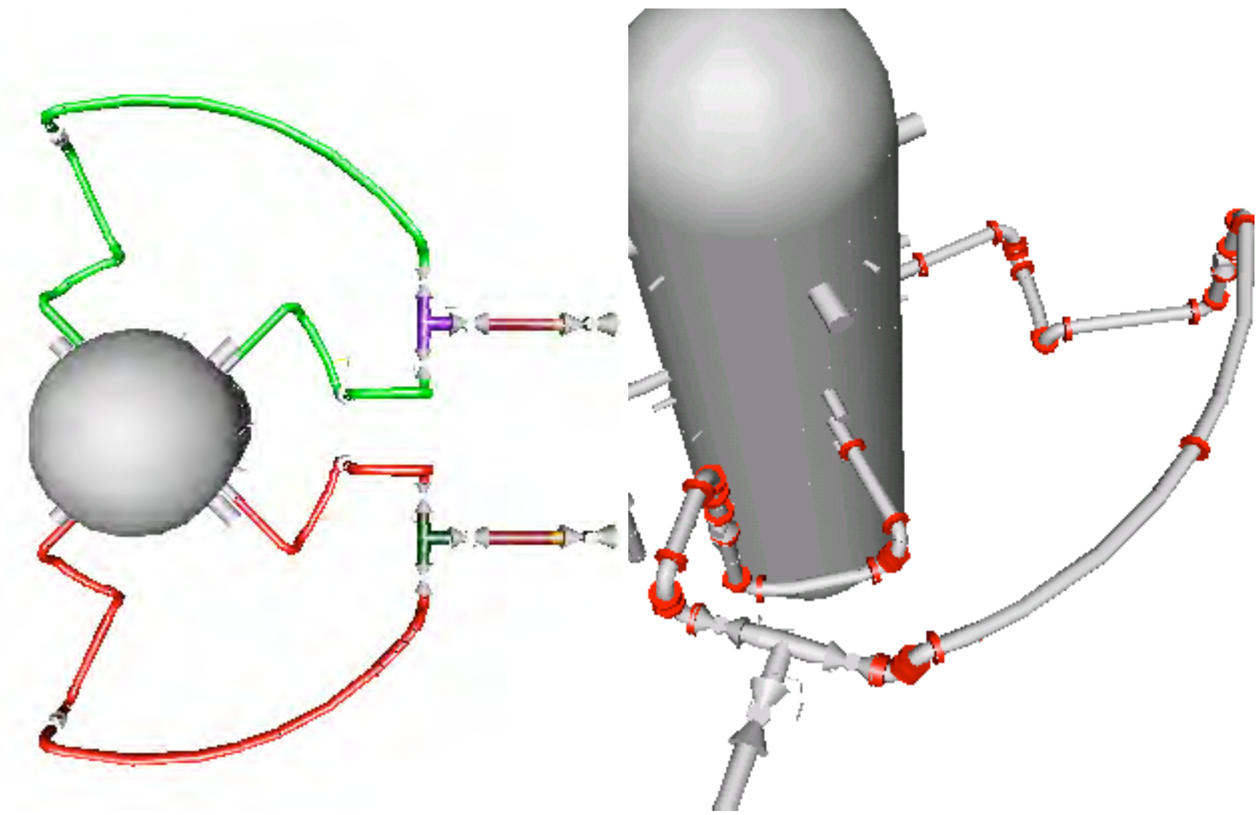
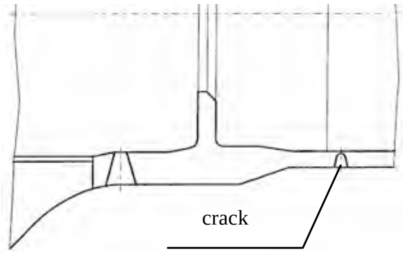


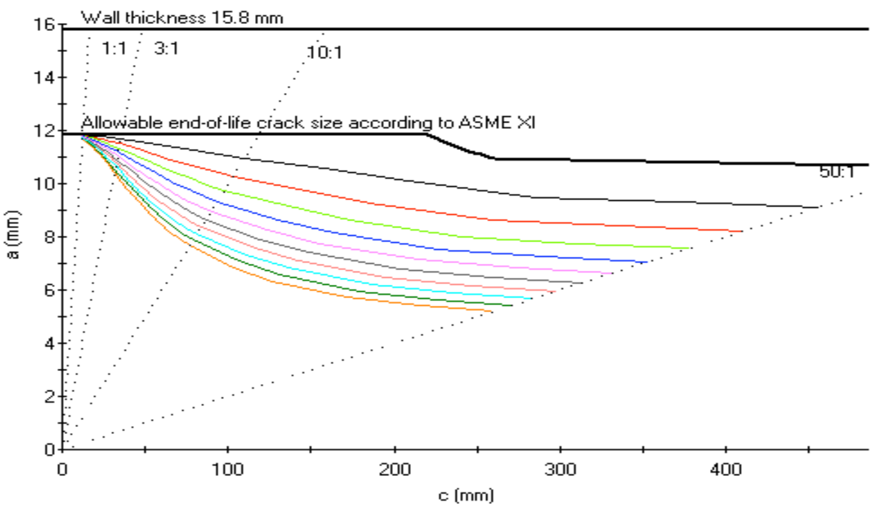
Fig. 8, PAMS piping model generated segment division for the feedwater lines and the visualized risk class for one of the segments.

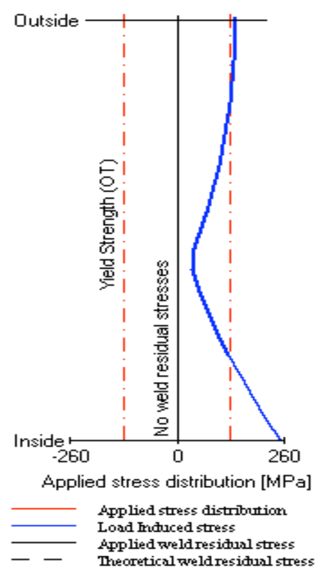
Fracture Analysis

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 have been performed performed using the VTT-BESIT program [5] but the indata file is still made partly by hand. This program will be fully connected to the PAMS system in 2009.

Location	312-Nozzles Safe end/Pipe weld
Material used for the analysis	SA376 type 304
$D_i/D_o/t$ [mm]	292/323.6/15.8
Flaw Characteristics	Internal circumferentially orientated crack
Specified crack a/c [mm]	
Degradation mechanism	Fatigue induced cracking
Crack growth law	$da/dN = C \cdot (\Delta K_I)^n$, C = 2.467E-08 , n = 3.82
Applied software	VTTBESIT 2.0
Weld residual stresses	None
Allowable crack determination	ASME sect. XI, div. 1, app. C, C-3000 /20/
Reference(s)	/13/







Curves showing for a crack growth time of 0 to 10 years what cracks will grow to the allowable end of life crack. The colour codes used in the diagram are defined in the table below.

years / c/a	1	2	3	4	5	6	7	8	9	10
1	11.83	11.82	11.80	11.78	11.77	11.75	11.73	11.72	11.70	11.68
2	11.81	11.76	11.72	11.67	11.63	11.59	11.55	11.51	11.47	11.43
3	11.77	11.69	11.61	11.53	11.45	11.38	11.31	11.24	11.18	11.11
4	11.57	11.30	11.06	10.84	10.64	10.45	10.28	10.11	9.96	9.81

Fig. 9, presentation of the short documentation for a crack growth analysis.

BOOKKEEPING AND VALIDATION

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

PROJECT ORGANISATION, TIME SCHEDULE AND PRESENTATION OF THE PROJECT

During the first years, TVO was the sole contributor to the project and developed the document database and the material database and started the pipeline database. In this time the interface was still alphanumerical. For some years the project was a joint effort of TVO, VTT and FEMdata, but now it is mainly TVO taking care of the development. In the project "Lifetime of pressure retaining components" [2] and its successor projects a practical toolbox consisting of computational and experimental tools is generated for effective condition monitoring of process piping and estimation of its remaining lifetime. New features to the pipeline database are: the development of the visual interfaces, 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 ANSYS. As a part of the project, the FPIPE program is further extended and tailored to optimally fit the analysis and monitoring needs.

Developments for the near future are the crack growth analysis 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.

Recent Developments, Past Years

- Visualisation of any property coupled to a node or element. Both static and transient input properties can be visualised. In the future also result properties can be visualized
- Sophisticated routines to couple primary and secondary source references to the data in the database.
- Writing to and reading from the result database as well as the associated bookkeeping.
- Development of a new generation of the loading database.

Topics For Future Studies And Development

- Transient thermal- and flow analysis and flow induced loads, like water hammer or pump transients and pipe break loads. Will it be possible to generate an input file to a thermo-hydraulic program and write the analysis results back into the database?
- Back coupling of pressure and temperature measurements. The inside temperature transients to be determined from the measured outside temperature transients. A study on available techniques and tools will be performed and the possible application studied.
- Coupling of a program performing EN/PED piping and component analysis according to the EN Standards.
- Bimetallic weld analysis. This would involve a complicated FEM analysis to be coupled to the database. Some efforts have been made to make 3D model macros for Tees.
- Transient and event monitoring based on events and/or measurements.
- Bookkeeping of inspection results.
- Multiple run development.
- Valve strength analysis.
- Coupling of the VTT-BESIT fracture analysis program to PAMS.

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