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► **To cite this version:**

Jean-claude Debus. The capabilities of the new version of ATILA. Uchino K., Debus J.C. Applications of ATILA FEM software to smart materials : case studies in designing devices, Elsevier, pp.25-44, 2012, ISBN 978-0-8570-9065-2. 10.1533/9780857096319.1.25 . hal-00798908

HAL Id: hal-00798908

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Submitted on 24 May 2024

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The capabilities of the new version of ATILA

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Abstract: The aim of this chapter is to compare the new version of ATILA (ATILA++) with the previous one. In Section 2.3, the new developments in the pre- and post-processor are presented. Then in Section 2.5, a time comparison is made from several examples. With a first example which is a 3D electromechanical structure, the CPU and real times are compared for the computation of the 10 resonance and anti-resonance frequencies and for a harmonic analysis of 30 frequencies. The second example concerns a fluid harmonic analysis with 30 frequencies of a piezoelectric transducer. A thermal harmonic analysis is performed on a piezoelectric cylinder. Using the same cylinder, a transient analysis is carried with 100 time steps. For each analysis, the CPU and real times are presented and a comparison is made between the two versions.

Key words: finite-element, analysis, modal, harmonic, transient, transducer.

2.1 Introduction

ATILA is a finite element code that has been specifically developed to help in the design of sonar transducers, but it can also be used for all types of transducers¹ (industrial machining, cleaning, welding, nondestructive testing, acoustic imaging, actuators) or for passive structures. Its working domain is one of small and linear strains. It permits the static, modal, harmonic and transient analyses of unloaded elastic, piezoelectric, magnetostrictive or electrostrictive structures. It also enables the harmonic and transient analyses of radiating elastic or piezoelectric structures (in any fluid, water or air, for example) and modal or harmonic analysis of periodic structures with 1D, 2D or 3D periodicity. Moreover, it can perform analyses of axisymmetrical, 2D or 3D structures. Depending upon the problem, it provides: the displacement field, the nodal plane positions, the stress field, near-field and far-field pressures, transmitting voltage response, directivity patterns and the electrical impedance. Its ability to describe the behaviour of different transducers (Tonpilz transducers, double headmass, axisymmetrical length expanders, free-flooded rings, flextensional transducers, bender-bars, cylindrical and trilaminar hydrophones) and the accuracy of the results have been checked by modelling many different structures and comparing numerical and experimental results. Most results have been described in numerous reports, papers and articles; some of them are listed in reference 2.

ATILA is the result of many years of research, the first thesis was the start of this code with J. N. Decarpigny²; more than 20 PhD theses have contributed to the development of the ATILA code.

ATILA is mainly written in standard FORTRAN 77, except for some system interfacing written in C. It comprises more than 220 000 lines of code (including 4000 lines of C code). It has been carefully designed to be easily portable on almost all platforms. It was developed on an IBM 370 series mainframe (VM/CMS), it is maintained at ISEN on IBM-PC compatible computers (64-bit applications under Windows 98, Windows NT, Windows 2000, Windows XP and Linux) or Apple computers.

2.2 The new version of ATILA

A newer version of ATILA with new solvers that result in significantly faster computing times is proposed. A finite element calculation process solves systems of equations. In ATILA, according to the type of analysis, three different solvers are used: LU or Cholesky decomposition procedure for static and harmonic analysis, Lanczos algorithm for modal analysis, and central difference, Newmark's, or Wilson's methods for transient analysis. The main improvement is reduction of the filling of sparse matrices generated by the analysis. A skyline storing scheme is used and consists in storing elements of the matrix in such a way that most of the zero elements are not stored. This reduces the amount of memory used to store matrices as well as reducing the number of calculations during the factorization process. The skyline storing scheme when used together with a direct solving procedure is well suited for FEM calculations. This is because FEM calculations generate sparse matrices with a symmetric structure and also because the skyline structure is preserved during the LU factorization. However, this method implies extra calculations mostly during the factorization process and this storage scheme has only a clear advantage over using fully populated matrices if these matrices are strongly sparse. It is possible to greatly reduce the amount of stored data by using programs for producing fill reducing orderings. Many algorithms presented in the literature seem to give better results than the ones currently implemented in ATILA. Note that if these algorithms could improve the calculation speed in ATILA in the case of harmonic and transient analysis, they will not be very efficient if eigenfrequencies of a transducer are to be found. Transducer models use coupled electric-mechanical-fluid equations. Electric constitutive relationships generate null entries in the mass matrix. Hence the mass matrix cannot be easily factorized using a gauss elimination procedure. Currently, a static condensation of electric equations is used in ATILA. It consists in eliminating electric equations using the electro-mechanical coupling equations. This significantly increases the amount of storage because the structure of the matrix is changed and

this makes reordering algorithms inefficient. There are two ways to solve this problem either by changing the storage scheme or reorganizing the way electric equations are accounted for.

Many other storage schemes are presented in the literature. For most of these, they are very efficient if used together with an incremental solving procedure. As discussed above we think that the direct solving procedure is very adequate due to the symmetric structure of matrices involved in FEM calculations.

In order to reorganize the way data are managed in the code, it is interesting to note that we are generally looking for the natural mode of the structure. Hence it is not necessary to hold electric equations during the eigenmode calculation – they must be accounted for during the factorization procedure. The new method is to organize equations in order to take into account the null entries in the mass matrix during the matrix factorization by eliminating electric equations during the eigenmode calculations. Using this method, it is possible to keep the symmetric sparse structure of the matrix and then efficiently use the ordering procedure to reduce the matrix filling. For the new version of ATILA called ATILA++, the used language is the C++.

2.3 Pre- and post-processor GiD

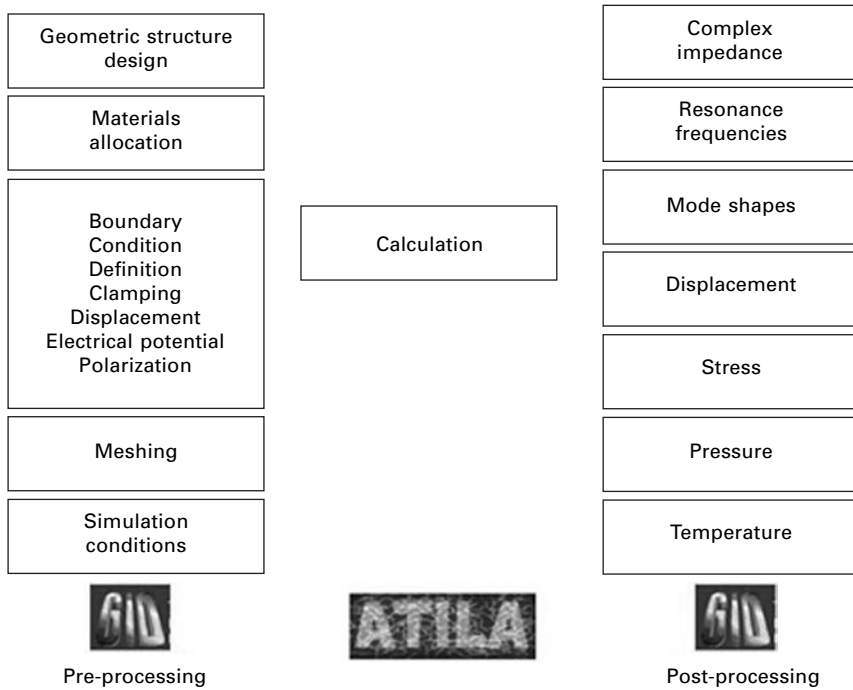
GiD³, developed by CIMNE, in Spain, is a universal, adaptive and user-friendly pre- and post-processor for numerical simulations in science and engineering. It has been designed to cover all the common needs in the numerical simulations field from pre- to post-processing: geometrical modelling, effective definition of analysis data, mesh generation, transfer data to analysis software and visualization of results.

GiD is an effective and easy-to-use geometric user interface. The GiD/ATILA interface supports the functions for applying boundary conditions (mechanical, electrical, thermal and magnetic) to the structure as well as defining materials. A material database of standard materials is included. Post-processing functions are numerous and varied: geometry and mesh visualization (including cuts), deformation, contour lines and colour maps, vectors, grids, animations, stress field, near-field and far-field pressures, transmitting voltage response, directivity patterns, electrical impedance. The ATILA code architecture⁴ is shown in Fig. 2.1.

2.4 New capacities in ATILA/GiD

2.4.1 Pre-processor

In the data menu, among the modifications, some icons have been altered to obtain a better choice of device analysis. Figure 2.2 displays the use of parallel

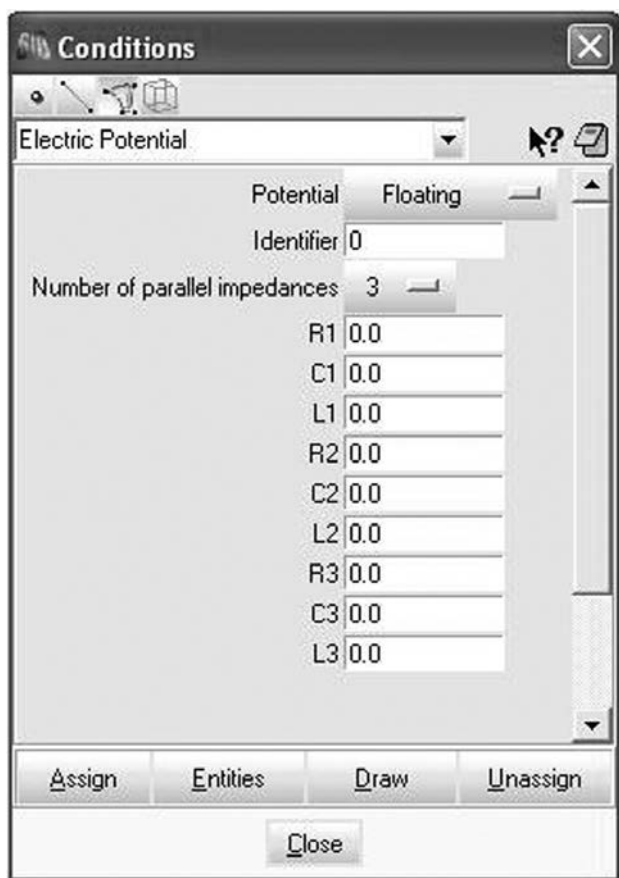


2.1 ATILA code architecture.

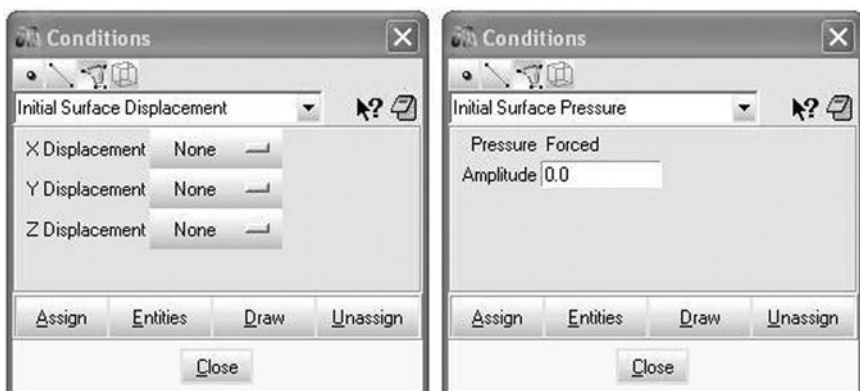
impedances for a piezoelectric ceramic. Up to three parallel impedances can be defined with resistors, inductors and capacitors. The initial surface or the line displacement and pressure can be imposed (Fig. 2.3).

With the material icon (Fig. 2.4), more items are proposed like the thin elastic patch, thin elastic piezo patch, elastic and anisotropic shell. When the thickness of a piece is very thin, a thin elastic patch can be used, it is a membrane element (Fig. 2.5). The thin piezo patch is used to model a macro fiber composite (MFC), the spacing between the fiber is defined. For example, Fig. 2.6 shows a clamped beam with a MFC patch. The contour fill of the z-displacement is displayed in Fig. 2.7. Figure 2.8 shows the elastic shell icon for a multilayer shell; with this icon, the number of layers can be given and for each layer, the thickness and the principal direction of the anisotropy are given as well. The elastic anisotropy properties are defined with the icon in Fig. 2.9. Figure 2.10 displays the contour fill of the z-displacement for a clamped multilayer beam. This beam has four layers of E-glass material, respectively, the orientation angles are 0° , 45° , -45° and 0° .

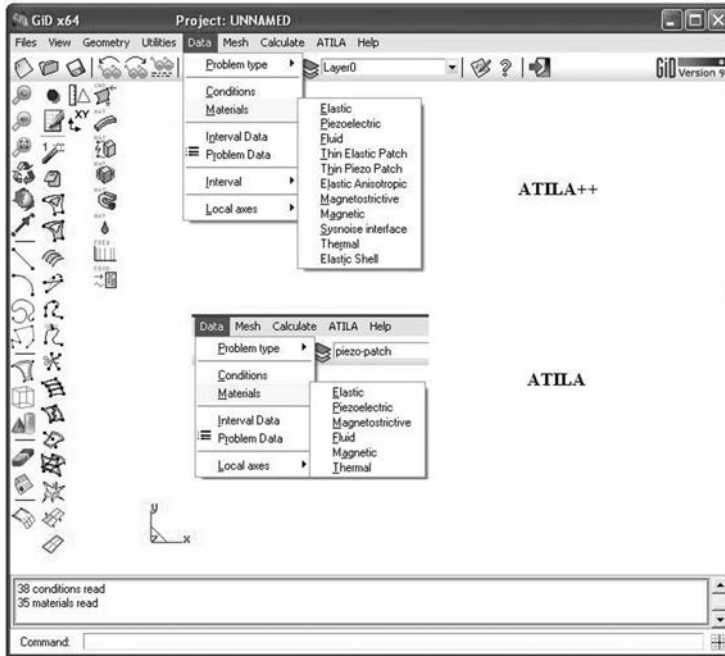
With the problem data item, an eigenvalue shift can be defined (Fig. 2.11); with this value, the eigenvalues before this value are not computed. For example, Fig. 2.12 displays a 3D flextensional transducer; the eigenvalues before 500 Hz will be not computed.



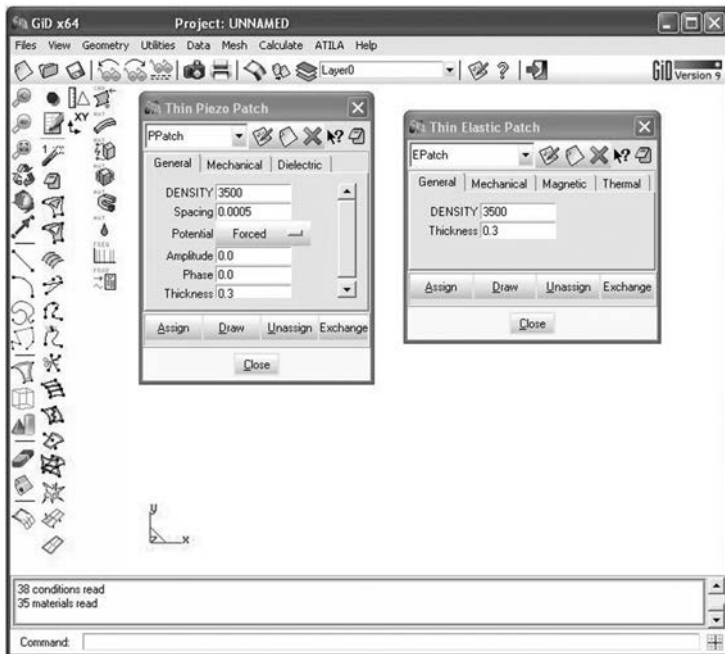
2.2 Condition icon: impedance.



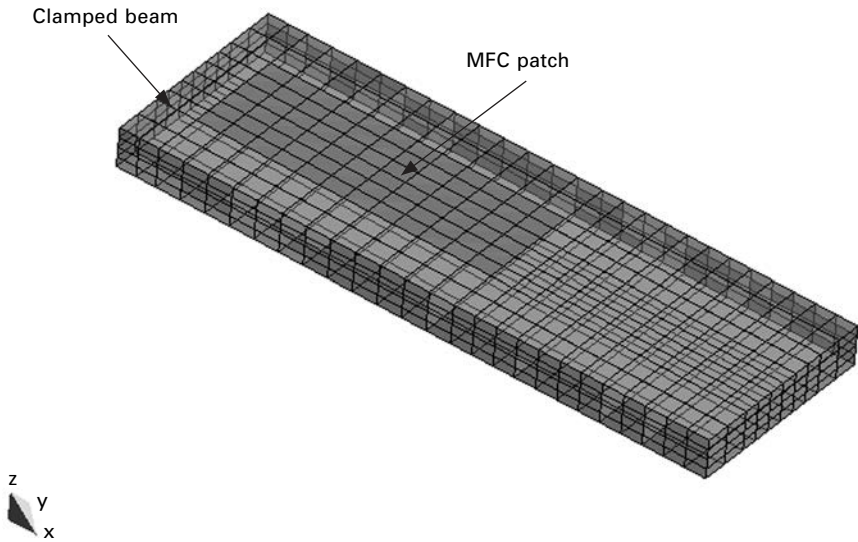
2.3 Condition icon: initial surface or displacement.



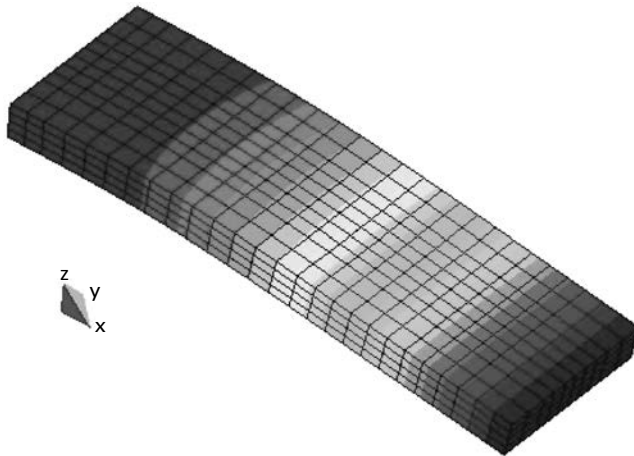
2.4 Material icon.



2.5 New icon: piezo patch and elastic patch.



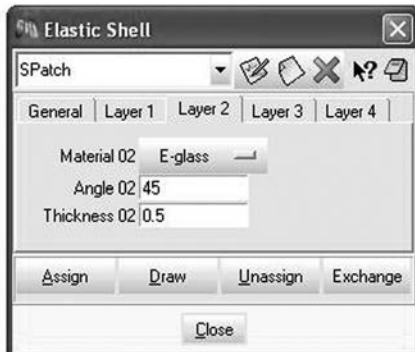
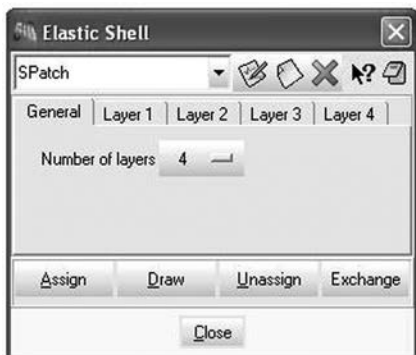
2.6 Clamped beam with a MFC patch.



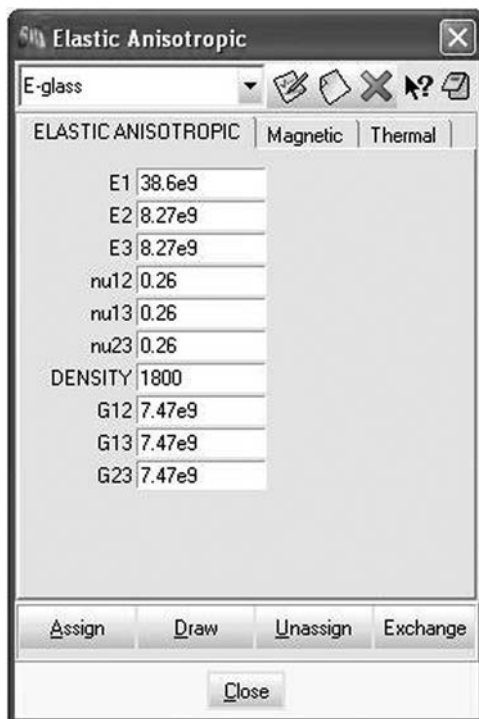
2.7 Contour fill of z-displacement.

2.4.2 Post-processor

Some modifications are shown in Plates III and IV (between pages 194 and 195), respectively, illustrating the contour fill of the strain and the contour of the far-field pressure.



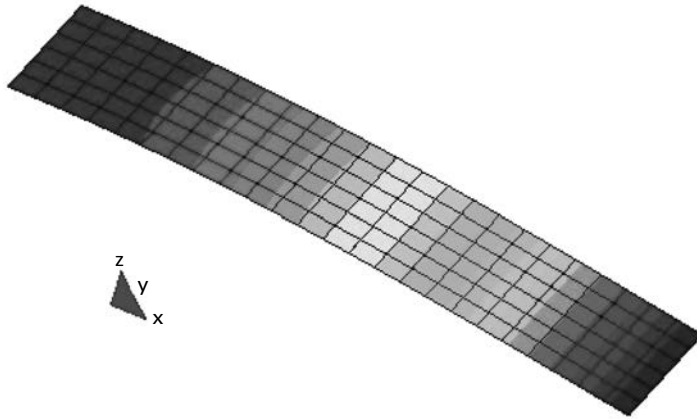
2.8 New icon: elastic shell.



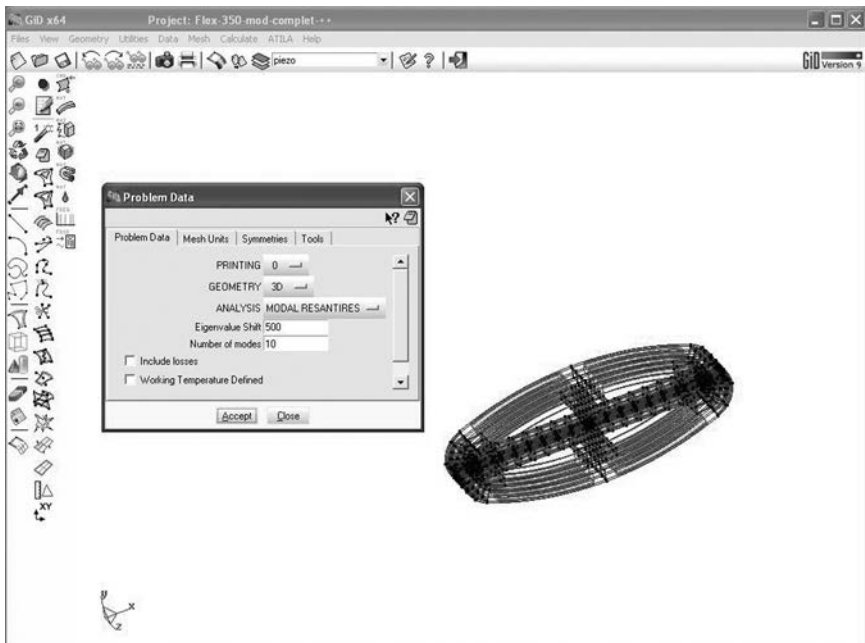
2.9 New icon: elastic anisotropy.

2.5 Time comparison between ATILA and ATILA++

The important amelioration of the new version is the speed of the computation. With these examples, several analyses have been performed and the computing times have been compared between the ATILA and ATILA++ versions.



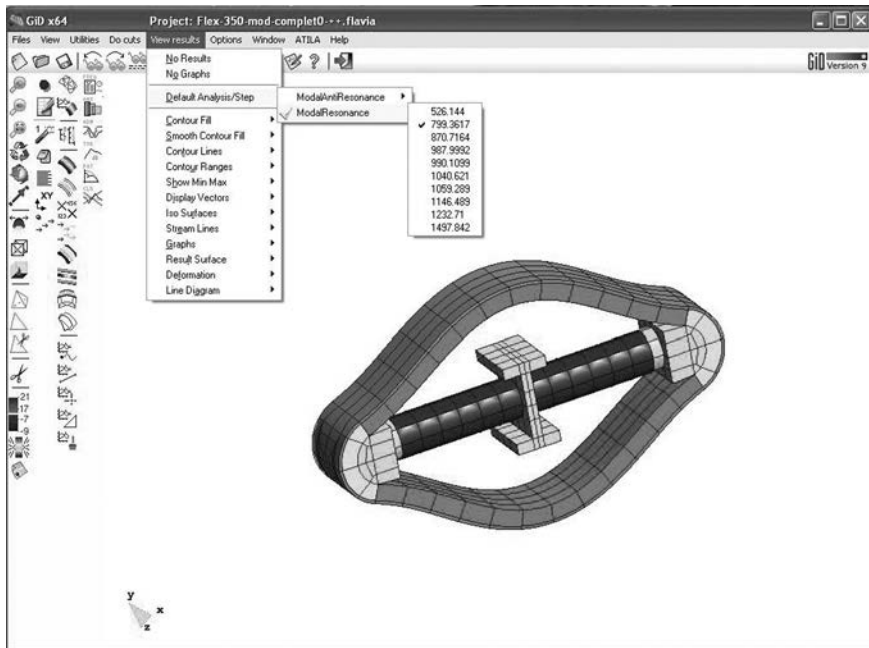
2.10 Contour fill of z-displacement of a clamped multilayer beam.



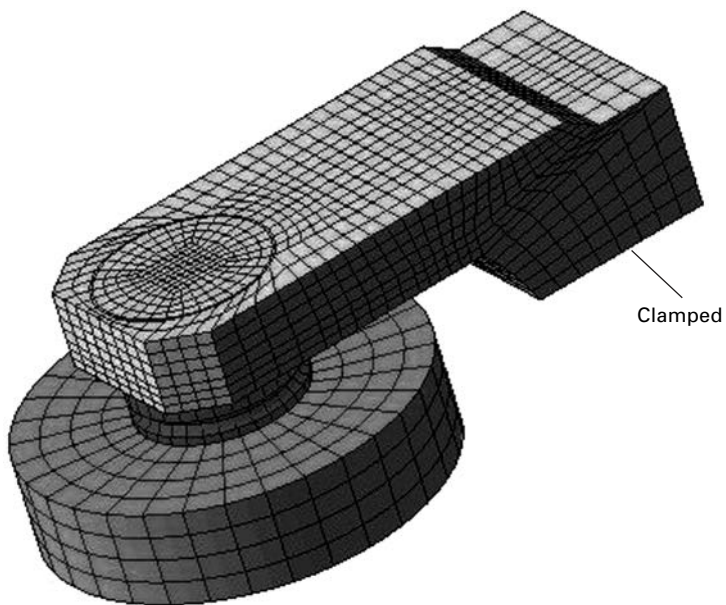
2.11 New item: eigenvalue shift.

2.5.1 Piezoelectric structure in air

The first structure tested for comparison is a 3D clamped structure with a piezoelectric plate and stacks in air (Fig. 2.13). The columns of Table 2.1 show, for seven different computations, respectively, the number of degrees of freedom, of nodes, and of elastic and piezoelectric elements. The last



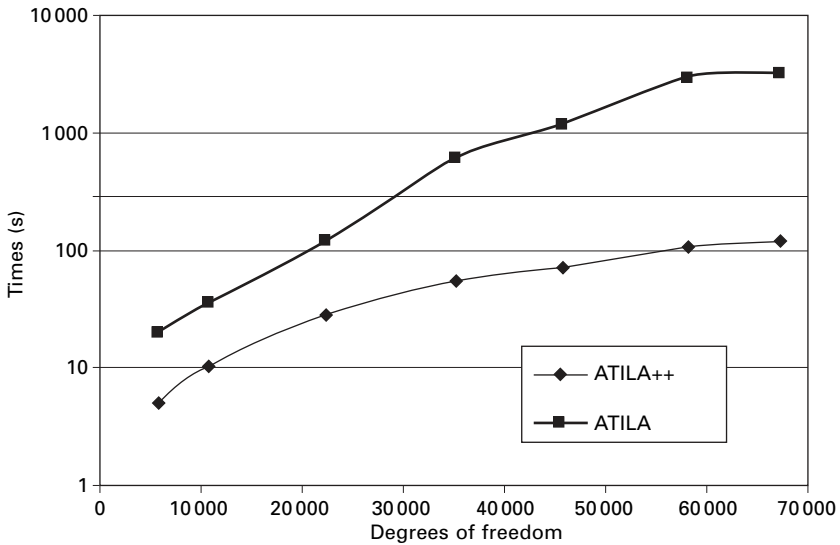
2.12 Modal resonance.



2.13 Piezoelectric structure-modal and harmonic analyses.

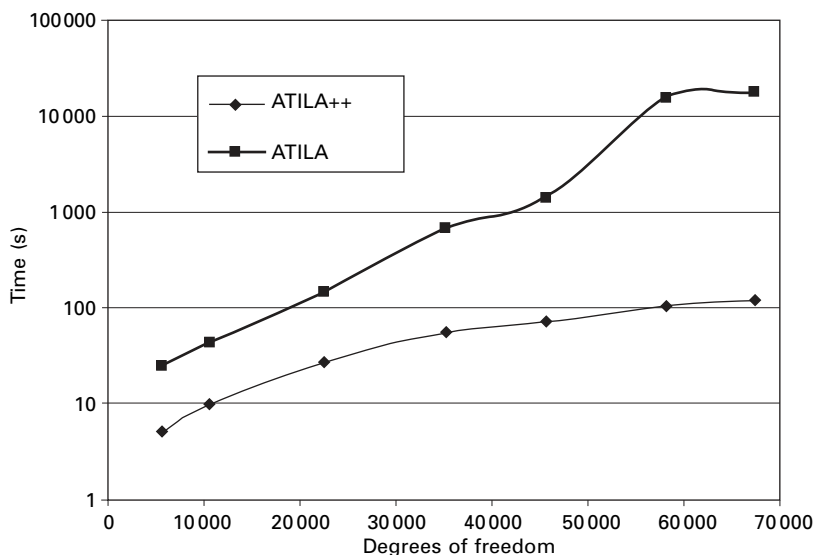
Table 2.1 Characteristics of the structure model

Degrees of freedom	Nodes	Elements		Blocks	
		Elastic	Piezoelectric	Modal	Harmonic
5 671	1 958	316	16	3	4
10 625	3 749	670	16	6	9
22 433	7 866	1 534	16	16	28
35 248	12 241	2 338	126	47	71
45 689	15 864	3 092	162	74	106
58 092	19 707	4 004	196	137	169
67 205	23 320	4 648	234	159	219



2.14 CPU time from a modal analysis for the structure.

two columns display the number of storage blocks used with the ATILA version, respectively, for modal and harmonic analyses. Figures 2.14 and 2.15 compare, respectively; the CPU and real times from a modal analysis versus the number of degrees of freedom, with 10 resonance and anti-resonance frequencies; the values of CPU and real times are shown on Table 2.2. The ratio of the computing real time between the ATILA and ATILA++ versions reaches 150. The results for a harmonic analysis with 30 frequencies are shown in Table 2.3 and in Figs 2.16 and 2.17. The real time ratio is near 100. Then, the last mesh for this structure has given 63 574 nodes, 13 802 elements and 186 486 degrees of freedom. The modal analysis has only been performed with ATILA++; the duration of the CPU time for 10 resonance frequencies is 340 s. Because of the size of the mesh, a computation with ATILA was not possible.



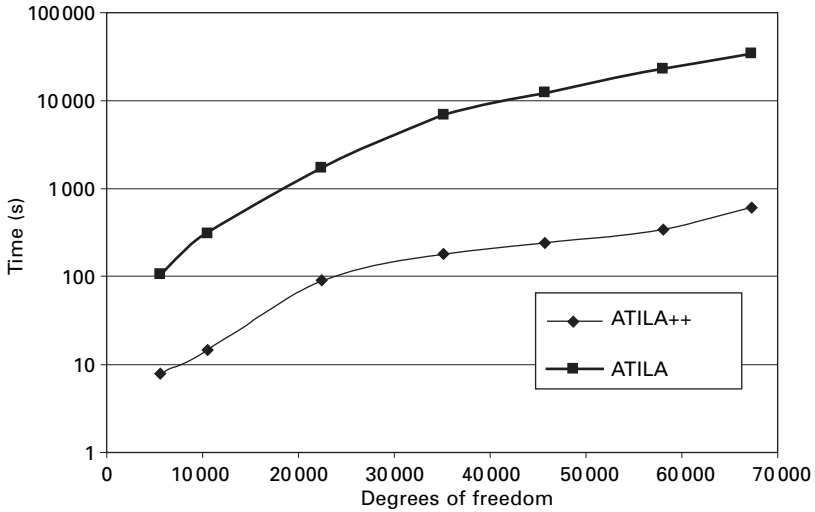
2.15 Real time from a modal analysis for the structure.

Table 2.2 CPU and real times of the modal analysis

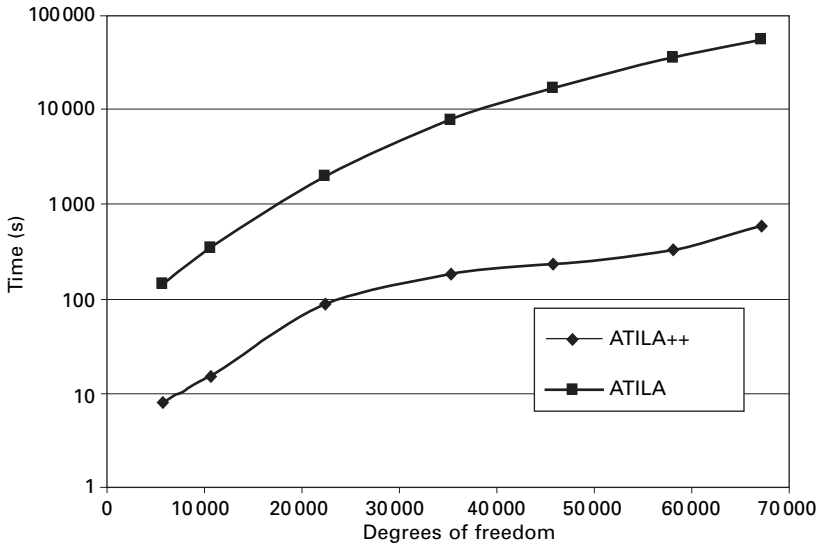
Degrees of freedom	CPU time (s)		Real time (s)	
	ATILA++	ATILA	ATILA++	ATILA
5671	5	20	5	25
10625	10	36	10	45
22433	28	120	28	145
35248	55	595	55	671
45689	72	1153	72	1398
58092	105	2927	105	15235
67205	120	3226	120	17952

Table 2.3 CPU and real times of the harmonic analysis

Degrees of freedom	CPU time (s)		Real time (s)	
	ATILA++	ATILA	ATILA++	ATILA
5675	8	106	8	146
10621	15	312	15	355
22429	90	1720	90	2026
35248	182	6711	182	7782
45689	240	12022	240	17681
58092	340	23109	340	35124
67201	603	34084	603	55476



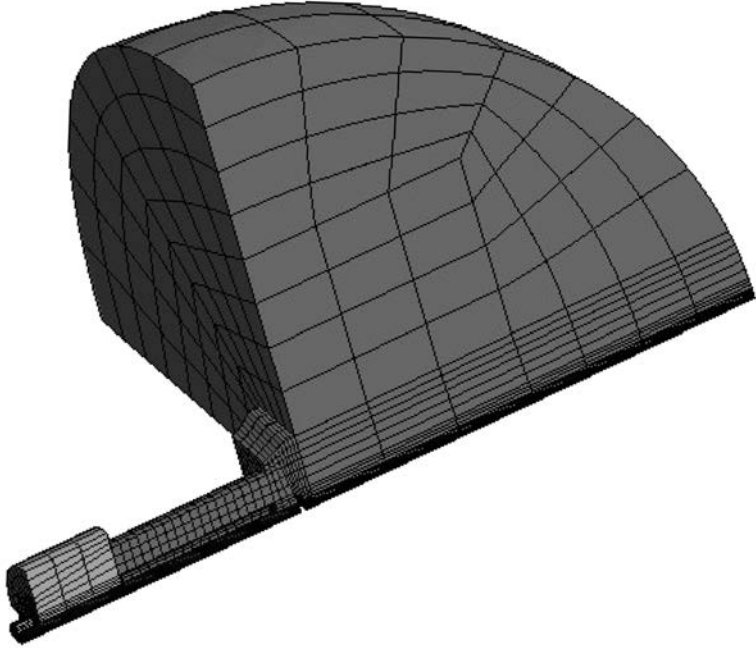
2.16 CPU time from a harmonic analysis for the structure.



2.17 Real time from a harmonic analysis for the structure.

2.5.2 Piezoelectric transducer in fluid

The second example concerns a piezoelectric transducer in water (Fig. 2.18). The characteristics of the numerical model are summed up in Table 2.4. The results of the CPU and real times are displayed in Table 2.5 and in Figs 2.19 and 2.20. The real time ratio is near 130. Another modelling has been



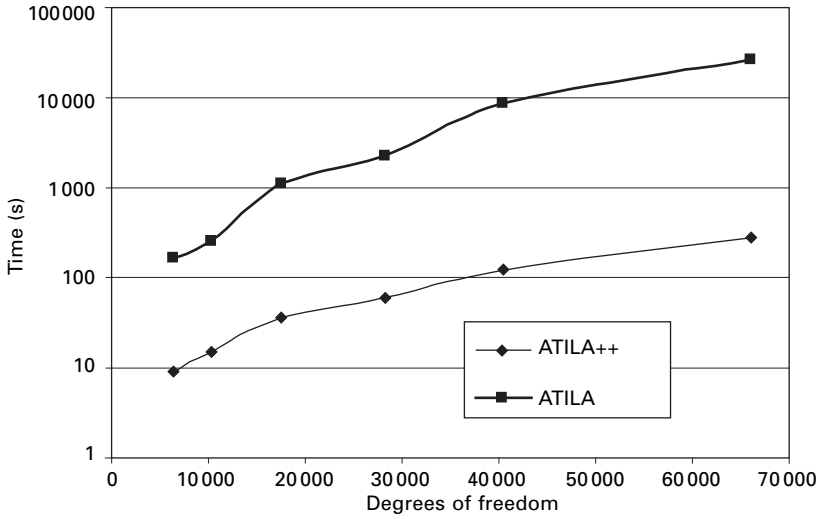
2.18 Piezoelectric transducer in water.

Table 2.4 Characteristics of the transducer model

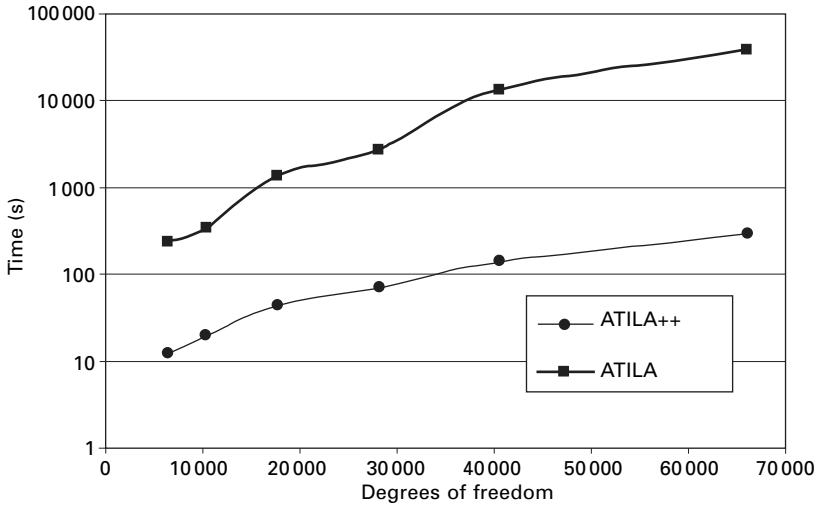
Degrees of freedom	Nodes	Elements			Blocks	
		Elastic	Piezoelectric	Fluid	Damper	Harmonic
6 453	3 090	276	48	228	52	5
10 240	4 877	400	96	380	60	8
17 633	8 278	750	144	696	99	21
28 212	12 776	1 312	192	1 104	144	37
40 574	17 313	1 872	432	1 216	168	83
66 172	27 169	3 200	768	1 680	208	187

Table 2.5 CPU and real times of the fluid harmonic analysis

Degrees of freedom	CPU time (s)		Real time (s)	
	ATILA++	ATILA	ATILA++	ATILA
6 453	9	166	12	237
10 240	15	254	20	343
17 633	36	1 121	44	1 326
28 212	60	2 310	71	2 744
40 574	125	8 738	140	13 672
66 175	273	27 014	299	38 052



2.19 CPU time from a harmonic analysis for the transducer.

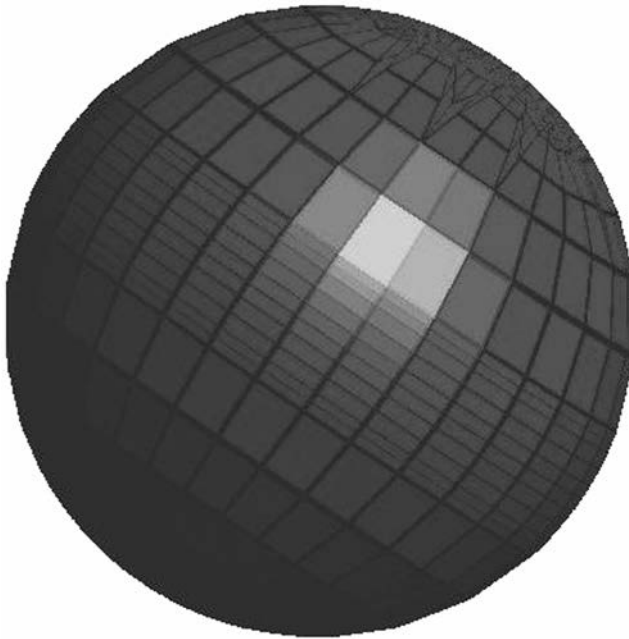


2.20 Real time from a harmonic analysis for the transducer.

performed to test the performance of the new version. This model is a cymbal transducer array. Figure 2.21 shows the array with nine cymbal transducers. The fluid mesh is presented in Fig. 2.22. The model is represented by 174051 nodes, 183304 elements and 232850 degrees of freedom. The CPU time for a harmonic analysis with 151 frequencies is 6720 s.



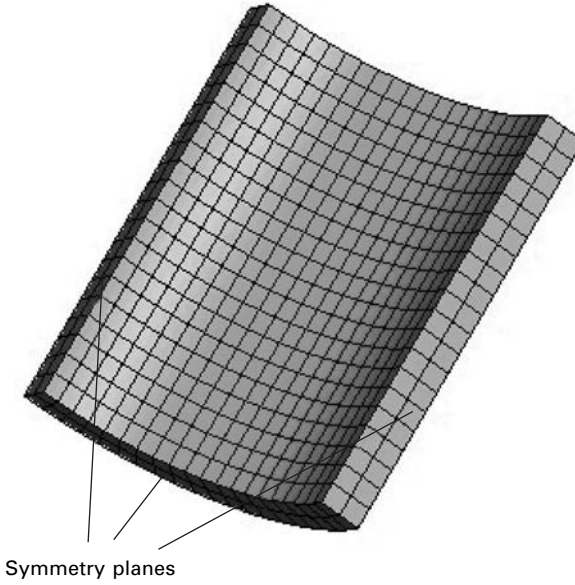
2.21 Deformed mesh of the cymbal array.



2.22 Fluid mesh of the cymbal array.

2.5.3 Thermal harmonic analysis of a piezoelectric cylinder

The last structure is a piezoelectric cylinder with three symmetry planes; only one eighth of the structure is modelled (Fig. 2.23). A thermal analysis with 30 frequencies is performed to compare the computing times between the two versions of ATILA. The characteristics of the numerical model are shown in Table 2.6 and the results are displayed in Table 2.7 and in Figs 2.24 and 2.25. The higher real time ratio is 286. A new modelling has permitted



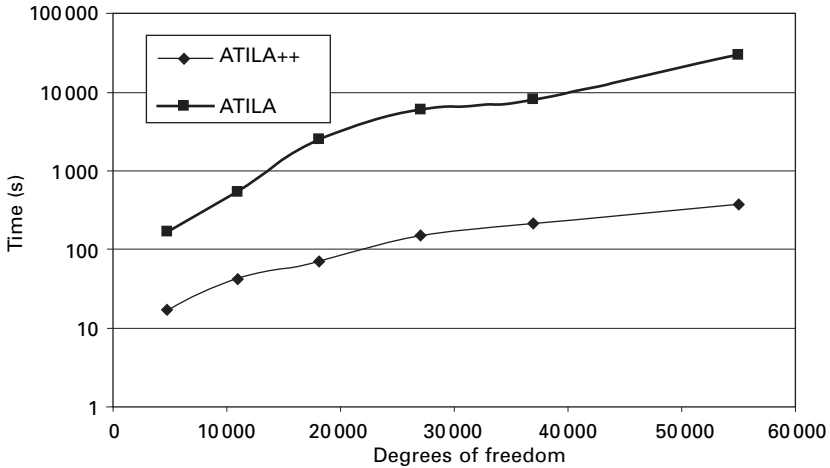
2.23 Piezoelectric cylinder.

Table 2.6 Characteristics of the cylinder model

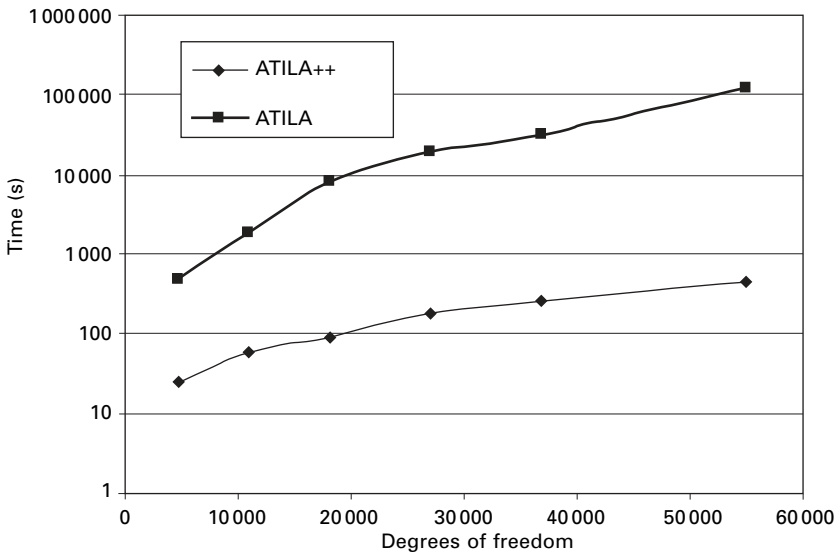
Degrees of freedom	Nodes	Elements		Blocks	
		Piezoelectric	Convection	Harmonic	Thermal
4 636	1265	200	220	4	1
10976	2901	480	504	9	1
18076	4725	800	840	26	1
27 058	7069	1320	940	52	2
36874	9557	1800	1260	68	3
54984	14 167	2700	1890	162	6

Table 2.7 CPU and real times of the thermal harmonic analysis

Degrees of freedom	CPU time (s)		Real time (s)	
	ATILA++	ATILA	ATILA++	ATILA
4 636	17	167	25	489
10976	42	514	58	1 802
18080	68	2 466	93	8 384
27 102	145	5966	182	19 675
36874	208	8 186	255	30 736
54984	364	30 160	438	125 205



2.24 CPU time from a thermal harmonic analysis for the cylinder.



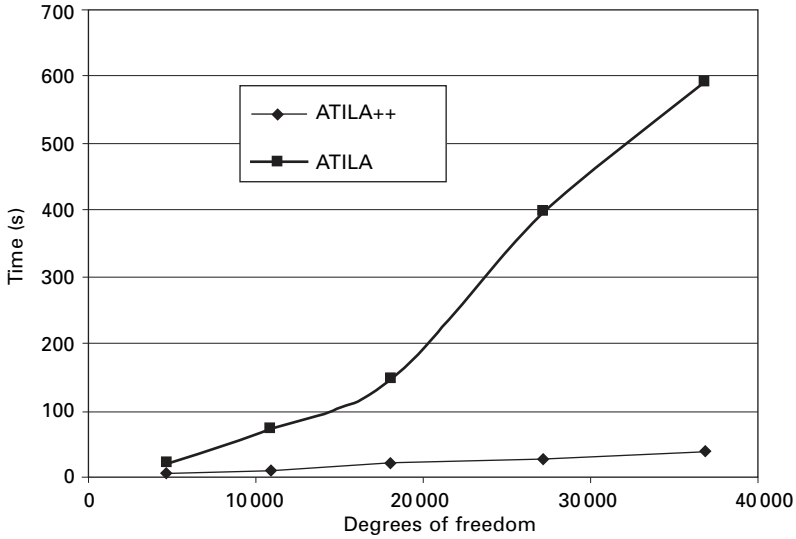
2.25 Real time from a thermal harmonic analysis for the cylinder.

to test the new version with a large mesh, 39 744 nodes, 8 100 elements and 155 786 degrees of freedom. The CPU time for this thermal harmonic analysis with 30 frequencies is 2 220 s.

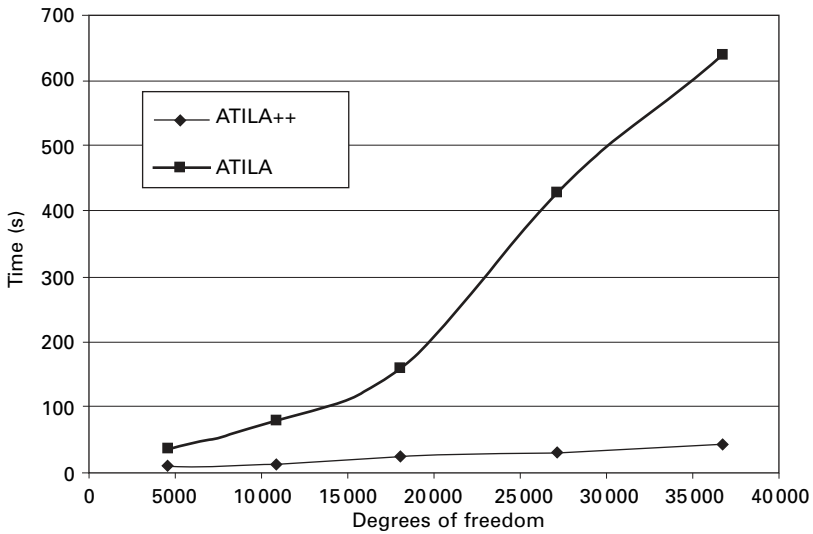
2.5.4 Transient analysis of a piezoelectric cylinder

With the same structure as previously, a transient analysis is performed, 100 time steps are computed using a direct integration method with the Newmark

method. Figures 2.26 and 2.27 display, respectively, the CPU and real times between the two versions of the ATILA code. The characteristics of the numerical model are shown in Table 2.8. Table 2.9 displays the results of the computation. The time ratios are 15. The same cylinder has been analyzed with a new mesh realized with 39744 nodes, 8100 elements and 155786 degrees of freedom, the CPU time for the new version is 650 s.



2.26 CPU time from a transient analysis for the cylinder.



2.27 Real time from a transient analysis for the cylinder.

Table 2.8 Characteristics of the cylinder model

Degrees of freedom	Nodes	Elements (piezoelectric)	Blocks (transient)
4 636	1 265	200	2
10 908	2 901	480	6
18 076	4 725	800	11
27 076	7 069	1 320	25
36 764	9 557	1 800	36
54 984	14 167	2 700	64

Table 2.9 CPU and real times of the transient analysis

Degrees of freedom	CPU time (s)		Real time (s)	
	ATILA++	ATILA	ATILA++	ATILA
4 636	7	20	8	37
10 908	10	73	11	81
18 076	21	147	24	160
27 076	26	394	30	427
36 764	38	591	43	638
54 984	81	1 099	90	1 208

2.6 Conclusion

From these different examples, the new version ATILA++ displays a significant improvement for a modal, harmonic or transient analysis. The time ratio between the two versions is very important. With this new version, the size of the mesh can be bigger than 200 000 elements with a reasonable CPU time.

2.7 References

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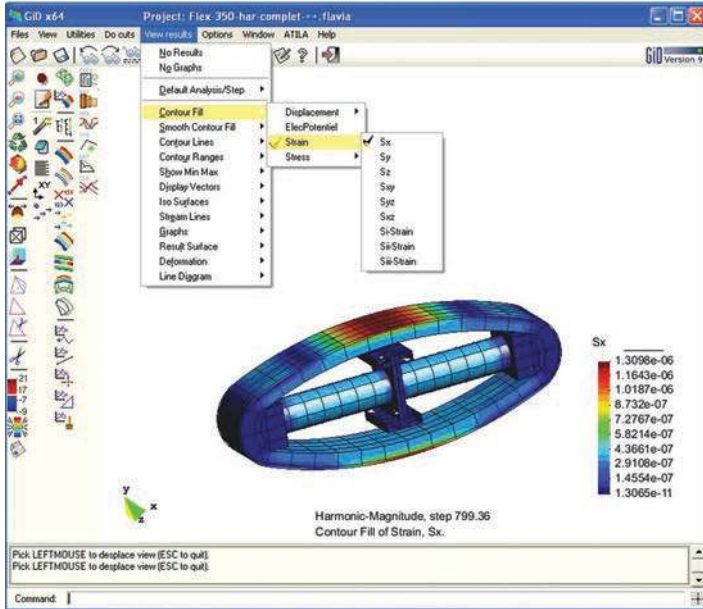


Plate III Contour fill of strain.

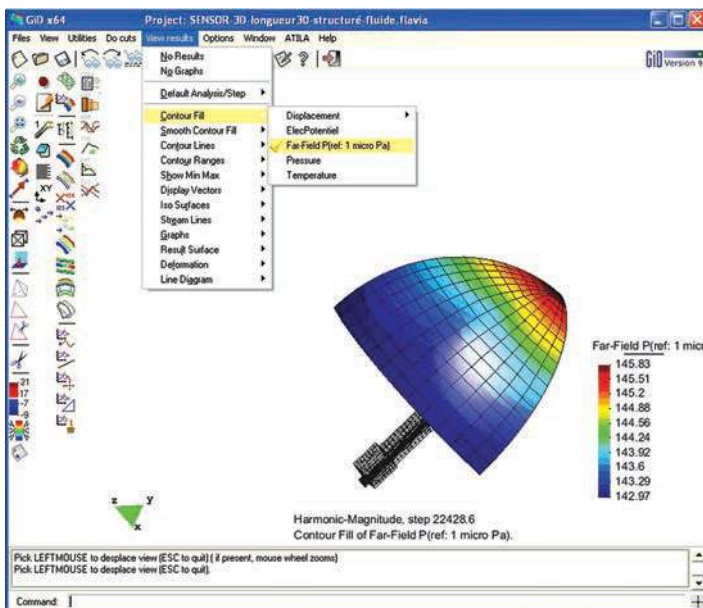


Plate IV Contour fill of far-field.