Computation of a model milling machine (mathematical model II)

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COMPUTATION OF A MODEL MILLING MACHINE

(MATHEMATICAL MODEL II)

C.I.R.P. Group Ma, Co-operative Work on
Computer Aided Design and Analysis of
Machine Tool Structures.

by

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1. INTRODUCTION

This report deals with the results of the computation of a model milling machine at the Eindhoven University of Technology. We started from the mathematical model (Fig. 1. and Table 1.) as proposed by the University of Louvain (Mathematical Model II). The computations were carried out at an EL-X8 digital computer with program A-4112 version 21.
The program language was Algol-60.

2. THE COMPUTERPROGRAM

The program is based on results obtained with the aid of the finite-elements-method. It is useful for the computation of the static and dynamic behaviour of arbitrary framed structures. Lumped masses as well as uniformly distributed mass can be taken into account.
The interesting stiffness-quantities of the elements are - in general - calculated from the length, the cross-sectional area, the second moments of area around the Y and Z axes and the material properties. However, the program offers the possibility to characterize some of the elements by direct input of the stiffness-quantities. Thus, it is possible to approximate hinges in the construction.
For further details see the report "Computation of a Model Milling Machine" of the Eindhoven University, which was presented to the C.I.R.P. Group Ma in Tirrenia 1970.

3. RESULTS OF THE COMPUTATION

3.1. General

For the computations we distinguish four versions of the mathematical model as pointed out in note 3 of Table 1. As can be seen, these versions differ only with respect to the elements 7, 9 and 30.

3.2. Static Results

Static deflection of all structural station points caused by unit forces applied between points 22 and 28 in X, Y and Z directions are calculated.
Table 2. and Figs. 2., 3. and 4. show the results of version 2.
The four versions of the model did not show a significant difference in the results as far as static loading is concerned.
The preparation time for static computations was 193 secs.
The computing time for one loading case was 22 secs. The computer was used in a time-sharing system.

3.3. Dynamic Results

We calculated the natural frequencies of the lowest 10 modes of vibration.
Figs. 5., 6., 7., 8., 9., 10., 11., 12., 13. and 14. show the results of version 2. In addition to this, Table 3. gives the natural frequencies of the respective modes for the four versions of the model.
The preparation and computing time for these 10 modes was approximately 2500 secs.

4. DISCUSSION

As pointed out earlier, we computed four versions of the mathematical model.
All these versions had uniformly distributed mass with lumped masses in some station points (see Table 1., note 2).
From a static point of view, the mathematical model seems to be reliable. However, there are some contradictions in the input data as distributed by Louvain, for instance:

- the term L/EIY for element 18 cannot be correct
- the remark "Shear influence is not taken into account" is not valid.

The input data of our computations are listed in Table 1.

Dynamically, there are more objections against the proposed model.
Especially, the quantities of the elements 7, 9 and 30 are to be considered more carefully. For example, the fifth mode of version 1 and 2, does not exist in version 3 and 4.

ELEMENT	L[m]	A[m2]	IY[m4]	IZ[m4]	J[m4]	M[kg]
1	0.0750	3.560E–4	0.1000E–4	0.2500E–4	0.7500E–2	0
2	0.2025	2.105E–2	0.2020E–3	0.7103E–3	0.3980E–3	33.25
3	0.1175	2.105E–2	0.1551E–3	0.5602E–3	0.3100E–3	19.39
4	0.0850	2.105E–2	0.1551E–3	0.5602E–3	0.3100E–3	13.95
5	0.0355	–	–	–	–	0
6	0.1150	1.787E–2	0.1054E–3	0.3969E–3	0.2150E–3	16.02
7	0		see note 3			0
8	0.2270	–	–	–	–	0.70
9	0		see note 3			0
10	0.1150	–	–	–	–	0
11	0.0850	–	–	–	–	0
12	0.2625	–	–	–	–	0.70
13	0.1750	1.187E–2	0.7587E–4	0.7396E–4	0.1030E–3	16.20
14	0.1400	1.187E–2	0.7587E–4	0.7396E–4	0.1030E–3	12.96
15	0.1600	–	–	–	–	0
16	0.2750	4.490E–3	0.5006E–5	0.1303E–4	0.6690E–5	9.63
17	0.2750	4.490E–3	0.5006E–5	0.1303E–4	0.6690E–5	9.63
18	0.2150	1.787E–2	0.1054E–3	0.3969E–3	0.2150E–3	29.96
19	0.0320	–	–	–	–	0
20	0.1950	1.501E–2	0.6016E–4	0.2434E–3	0.1290E–3	25.56
21	0.1950	–	–	–	–	2.95
22	0.1750	7.100E–4	0.3976E–7	0.3976E–7	0.7950E–7	0.97
23	0.1400	7.100E–4	0.3976E–7	0.3976E–7	0.7950E–7	0.78
24	0.1350	1.501E–2	0.6016E–4	0.2434E–3	0.1290E–3	15.81
25	0.950	–	–	–	–	0
26	0.1750	3.660E–3	0.4717E–5	0.1136E–5	0.1320E–4	5.00
27	0.1400	3.660E–3	0.4717E–5	0.1136E–5	0.1320E–4	4.00
28	0.3650	–	–	–	–	0
29	0.1350	3.420E–3	0.1042E–4	0.2681E–5	0.8680E–5	3.60
30	0		see note 3			0

Table 1.

L = length
A = beam cross sectional area
IY, IZ = second moment of area about Y and Z axes respectively
J = effective second polar moment of area

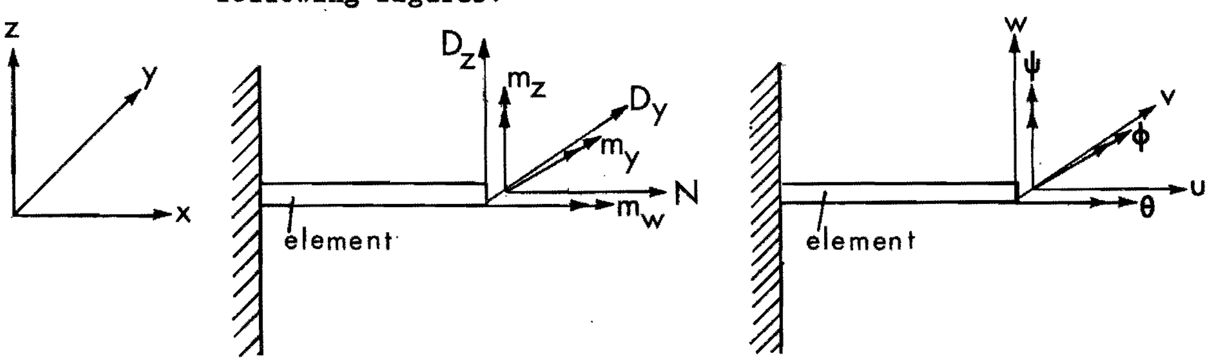
E = 2.10E+11 N/m2
G = 0.81E+11 N/m2
ρ = 7.8E+3 kg/m3

Note 1) The flexibility of the elements 5, 8, 10, 11, 12, 15, 19, 21, 25 and 28 is supposed to be negligible.

Note 2) The lumped mass data: in station point

station point	mass
1	60 kg
3	2 kg
6	2 kg
20	0.7 kg
24	13.9 kg

Note 3) In order to define the elements 7, 9 and 30 we consider the following figures:



forces and moments displacements and rotations

For the elements mentioned we define the following relation ship between forces and displacements in the respective versions of the model:

force	version 1	version 2	version 3	version 4
N	0.1E+14*u	0.1E+20*u	0.1E+14*u	0.1E+20*u
D_y	1.2E+14*v	1.2E+20*v	1.2E+14*v−0.6E+14*ψ	1.2E+20*v−0.6E+20*ψ
D_z	1.2E+14*ω	1.2E+20*ω	1.2E+14*ω+0.6E+9 * φ	1.2E+20*ω+0.6E+12*φ
m_w	0.1E+14*Θ	0.1E+20*Θ	0.1E+14*Θ	0.1E+20*Θ
m_y	0.4E+4 * φ	0.4E+4 * φ	0.4E+4 * φ	0.4E+4 * φ
m_z	0.4E+13*ψ	0.4E+19*ψ	0.4E+14*ψ	0.4E+20*ψ

station	Load in X direction			Load in Y direction			Load in Z direction		
point	X deflection	Y deflection	Z deflection	X deflection	Y deflection	Z deflection	X deflection	Y deflection	Z deflection
1	0	0	0	0	−.8814E−10	−.1165E−9	0	+.6445E−9	+.5042E−9
2	0	0	0	0	−.5695E−9	−.1219E−9	0	+.4263E−8	+.5272E−9
3	0	0	0	0	−.8611E−9	−.1249E−9	0	+.6513E−8	+.5405E−9
4	0	0	0	0	+.7089E−9	−.1286E−9	0	−.6423E−9	+.1985E−7
5	0	0	0	0	+.7083E−9	−.2274E−8	0	−.6423E−9	+.2685E−7
6	0	0	0	0	+.2772E−7	−.2280E−8	0	−.4986E−7	+.5762E−7
7	0	0	0	0	+.2772E−7	−.2280E−8	0	−.4986E−7	+.5762E−7
8	0	0	0	0	+.2772E−7	−.5338E−9	0	−.4986E−7	−.4620E−8
9	0	0	0	0	+.2772E−7	+.5338E−9	0	−.4986E−7	−.4620E−8
10	0	0	0	0	+.1128E−7	+.5338E−9	0	−.1745E−7	−.4620E−8
11	0	0	0	0	−.8611E−9	+.5338E−9	0	+.6513E−8	−.4620E−8
12	0	0	0	0	−.8611E−9	+.5338E−9	0	+.6513E−8	−.4620E−8
13	−.1150E−6	0	0	0	−.5892E−7	+.4801E−6	0	−.1745E−7	−.6742E−7
14	−.2531E−6	0	0	0	−.8592E−7	+.1267E−5	0	−.1745E−7	−.1625E−6
15	−.1877E−5	0	0	0	−.9587E−6	+.4801E−6	0	+.9122E−7	−.6742E−7
16	−.1877E−5	+.271 E−6	+.3028E−5	0	−.9587E−6	+.4801E−6	0	+.9122E−7	−.6742E−7
17	−.1877E−5	−.2711E−6	−.3028E−5	0	−.9587E−6	+.4801E−6	0	+.9122E−7	−.6742E−7
18	+.3533E−6	0	0	0	+.2212E−6	−.2280E−8	0	−.3080E−6	+.1149E−6
19	+.5121E−6	0	0	0	+.2212E−6	−.4208E−7	0	−.3080E−6	+.1699E−6
20	+.1281E−5	0	0	0	+.5121E−6	−.4208E−7	0	−.7809E−6	+.2318E−6
21	+.3595E−5	0	0	0	+.5121E−6	−.3572E−6	0	−.7809E−6	+.8423E−6
22	+.3390E−4	0	0	0	+.1544E−5	−.4640E−6	0	−.6050E−6	+.2226E−4
23	+.2782E−4	0	0	0	+.1429E−5	−.4186E−7	0	−.4643E−6	+.5209E−5
24	+.1863E−5	0	0	0	+.7292E−6	−.4204E−7	0	−.1247E−5	+.2562E−6
25	+.4781E−5	0	0	0	+.7292E−6	−.3528E−6	0	−.1247E−5	+.9902E−6
26	+.1390E−4	0	0	0	+.7568E−6	−.3802E−6	0	−.1281E−5	+.2964E−5
27	+.2525E−4	0	0	0	+.7789E−6	−.4203E−7	0	−.1308E−5	+.5102E−5
28	−.5896E−5	0	0	0	−.3011E−5	+.4801E−6	0	+.3391E−6	−.6742E−7
29	+.2782E−4	0	0	0	+.1429E−5	−.4186E−7	0	−.4643E−6	+.5209E−5
30	0	0	0	0	−.8611E−9	+.5338E−9	0	+.6513E−8	−.4620E−8

Table 2. Load +1000 N at 22 and −1000 N at 28 in the X, Y, and Z directions separately. The deflections are given in [m/1000N].

Mode	version 1	version 2	version 3	version 4
1	74	124	74	143
2	113	171	113	169
3	269	282	275	291
4	287	376	287	328
5	444	517	638	645
6	638	644	692	725
7	756	781	900	915
8	904	921	978	986
9	1073	1087	1087	1088
10	1087	1088	1286	1287

Table 3. Natural Frequencies [Hz] for the versions 1, 2, 3, and 4.

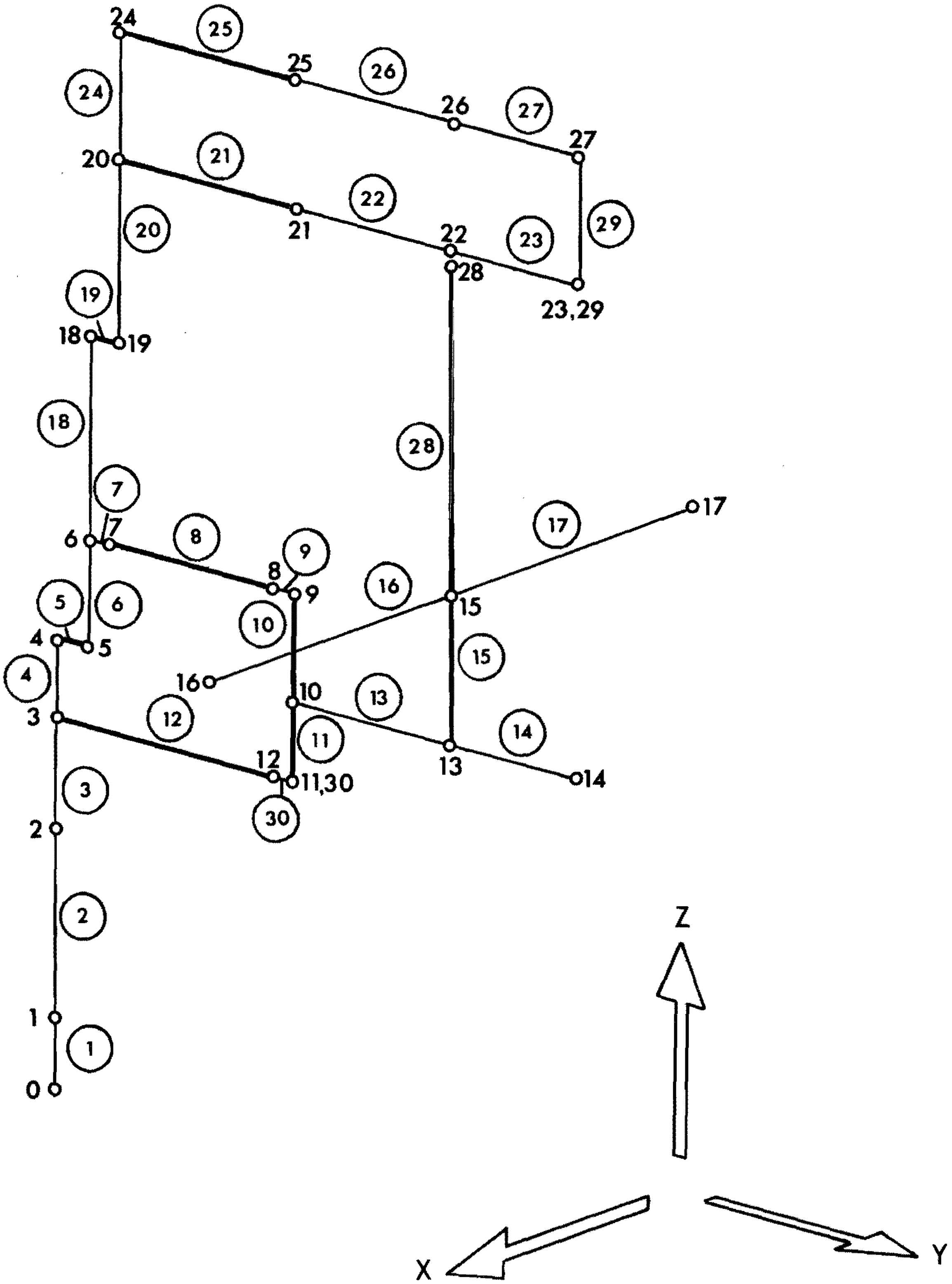


Fig. 1. Mathematical model II of the milling machine.

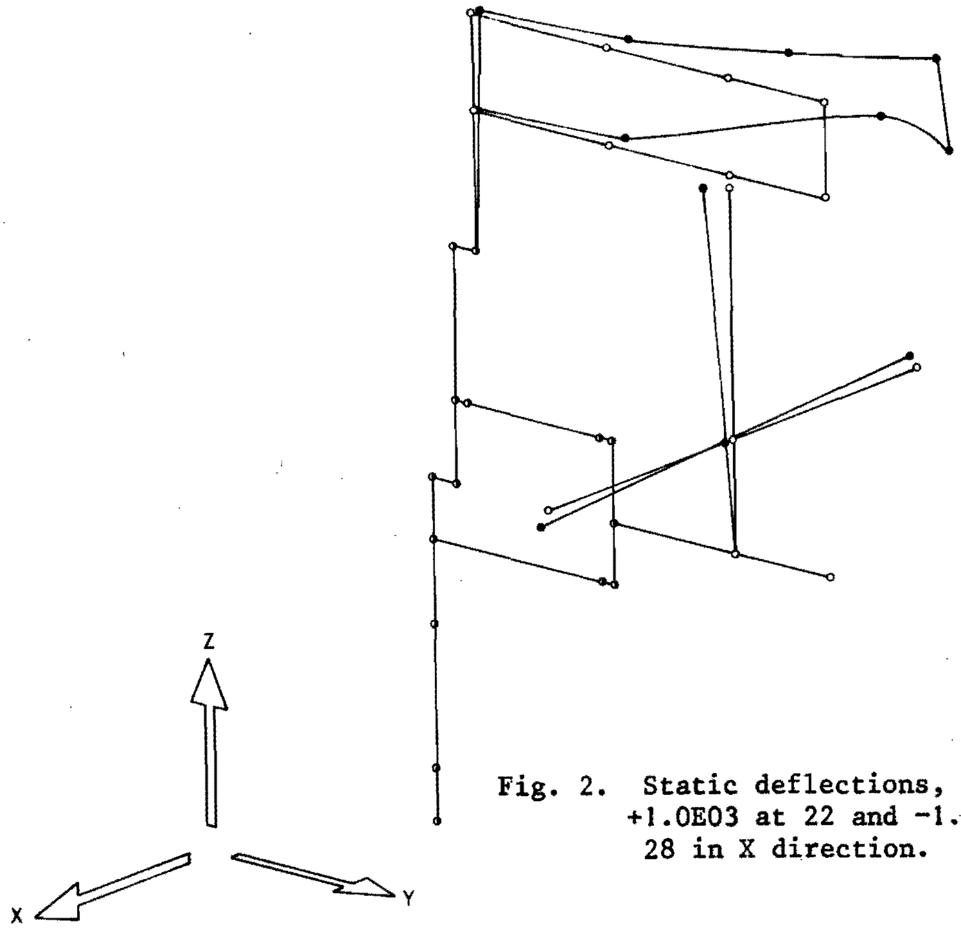


Fig. 2. Static deflections, load +1.0E03 at 22 and -1.0E03 at 28 in X direction.

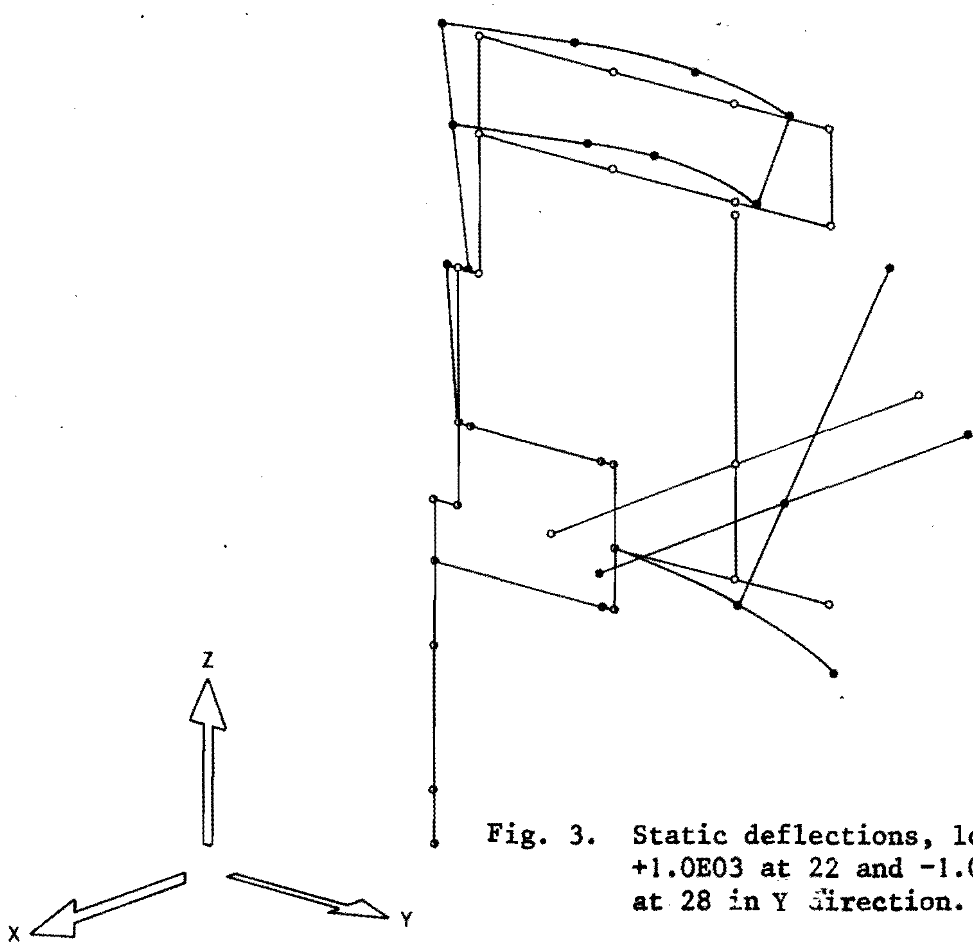


Fig. 3. Static deflections, load +1.0E03 at 22 and -1.0E03 at 28 in Y direction.

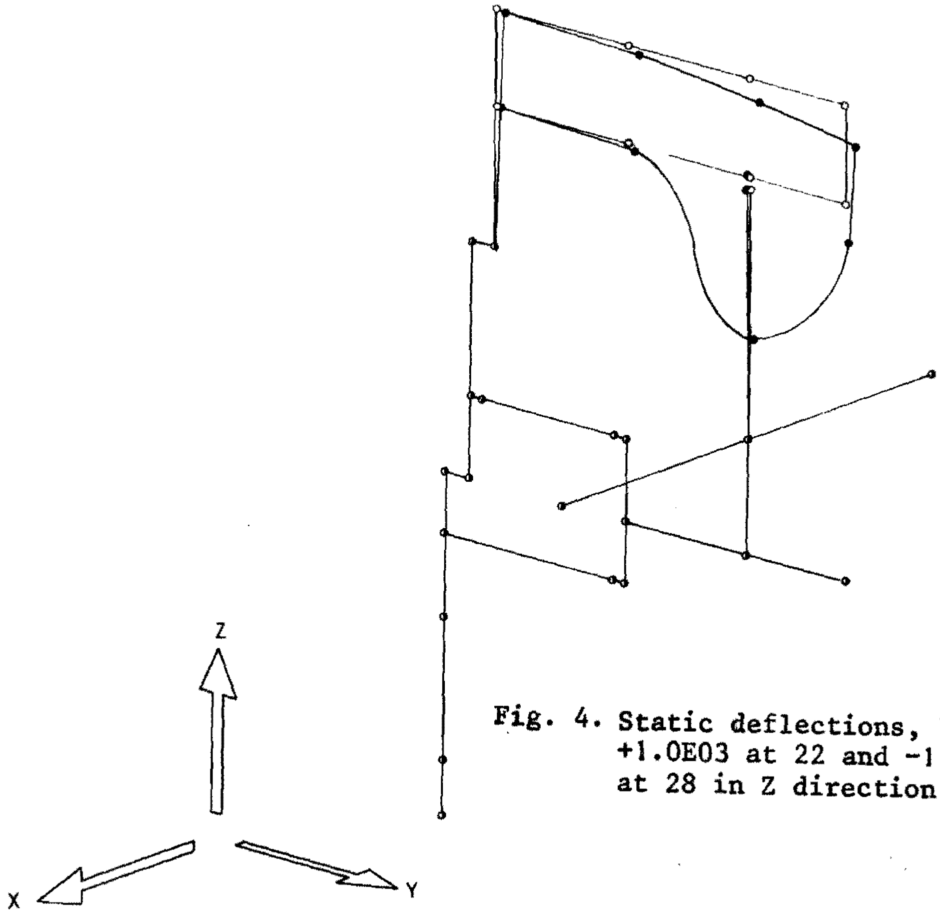


Fig. 4. Static deflections, load +1.0E03 at 22 and -1.0E03 at 28 in Z direction.

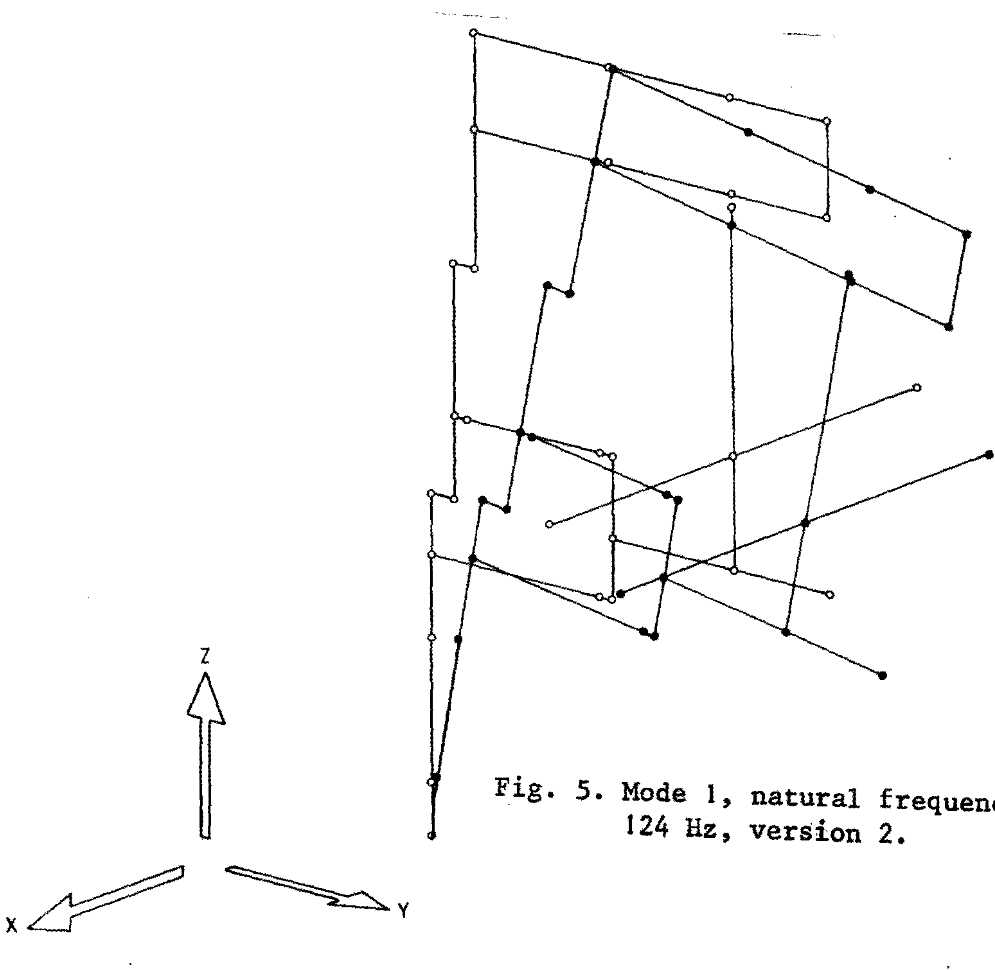


Fig. 5. Mode 1, natural frequency 124 Hz, version 2.

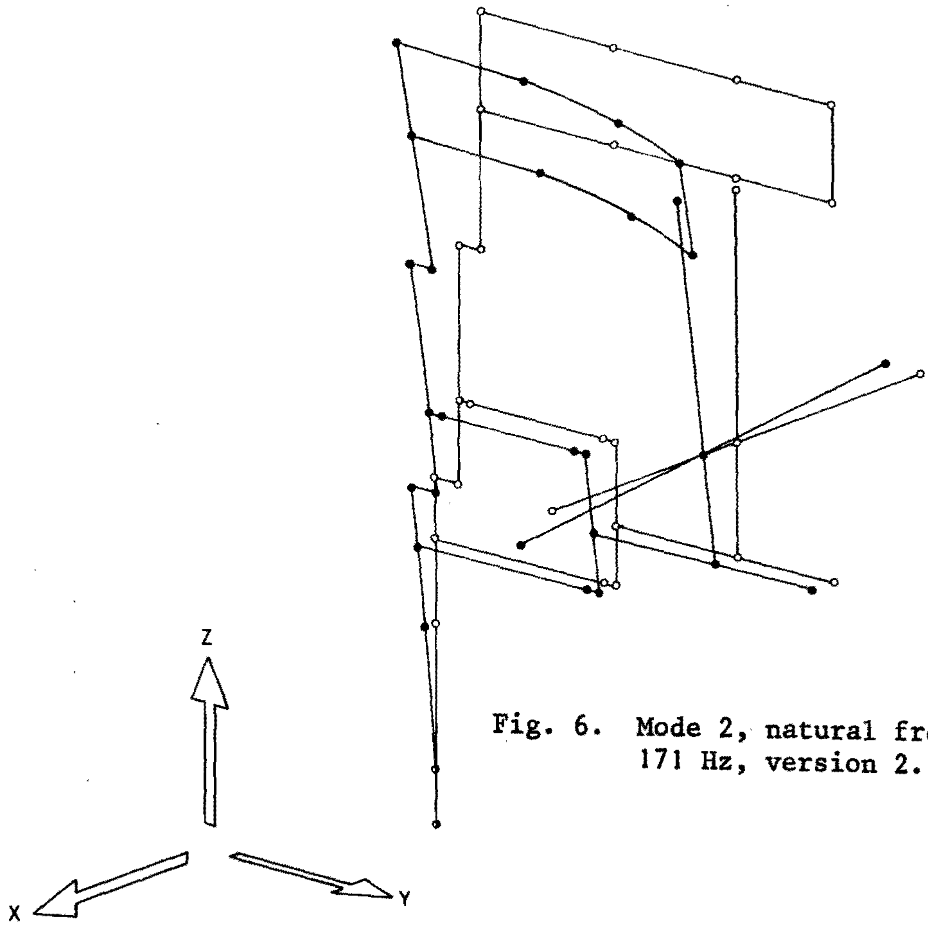


Fig. 6. Mode 2, natural frequency 171 Hz, version 2.

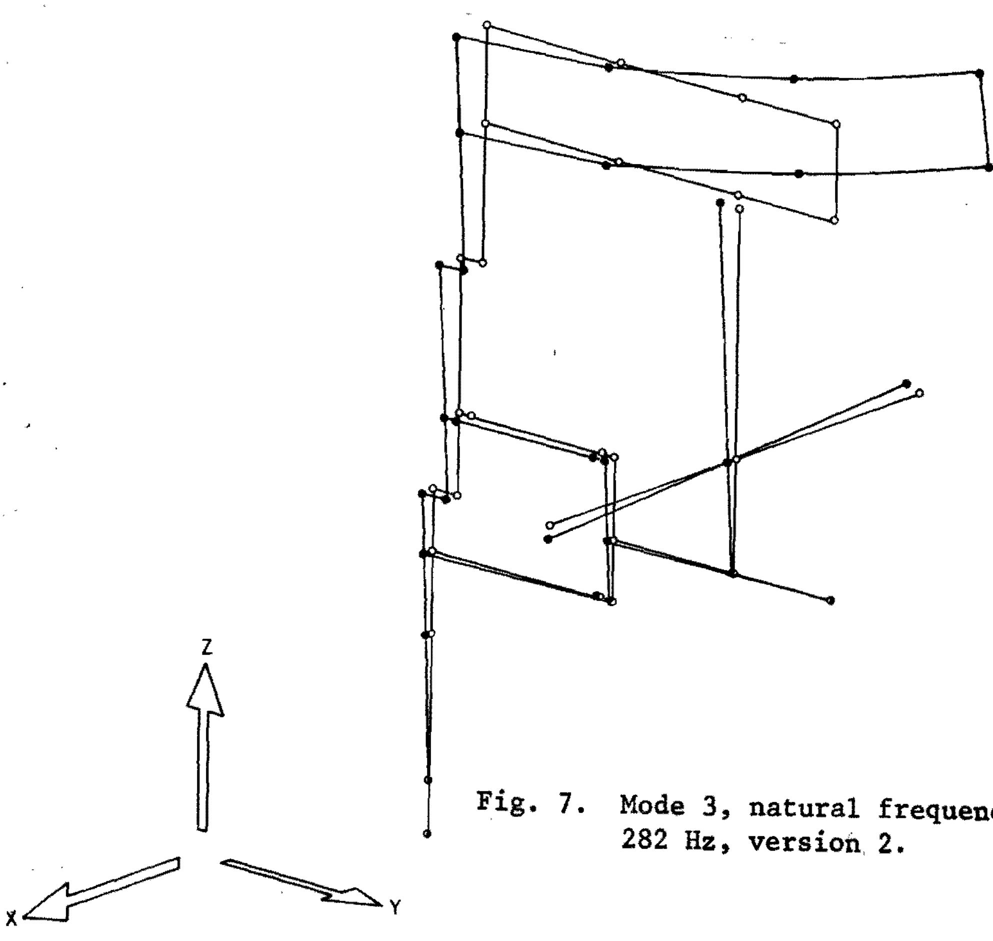


Fig. 7. Mode 3, natural frequency 282 Hz, version 2.

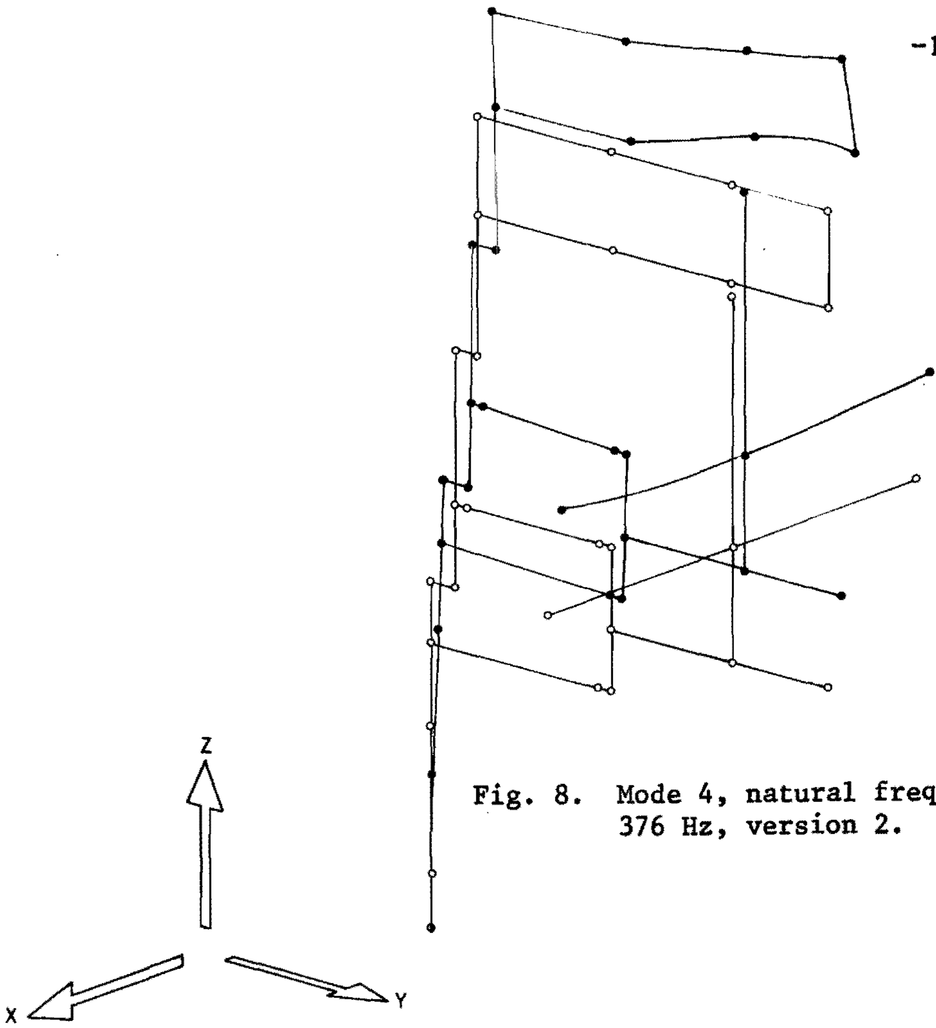


Fig. 8. Mode 4, natural frequency 376 Hz, version 2.

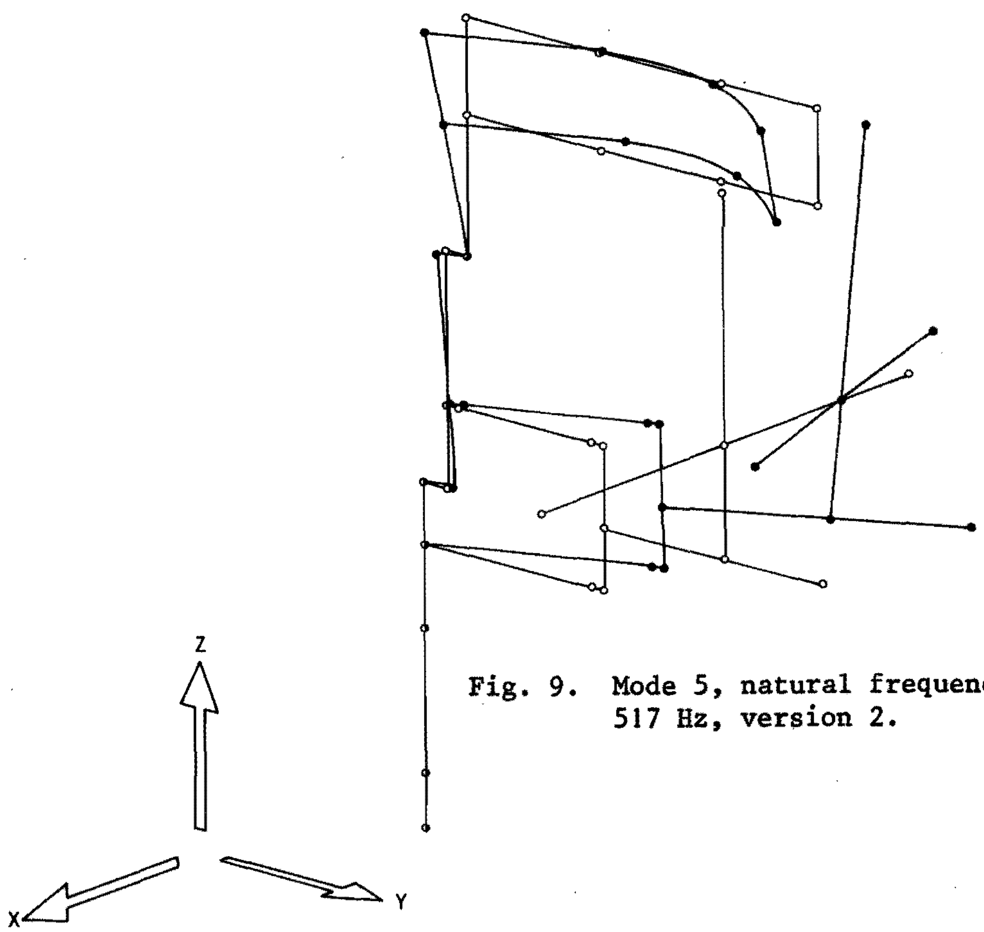


Fig. 9. Mode 5, natural frequency 517 Hz, version 2.

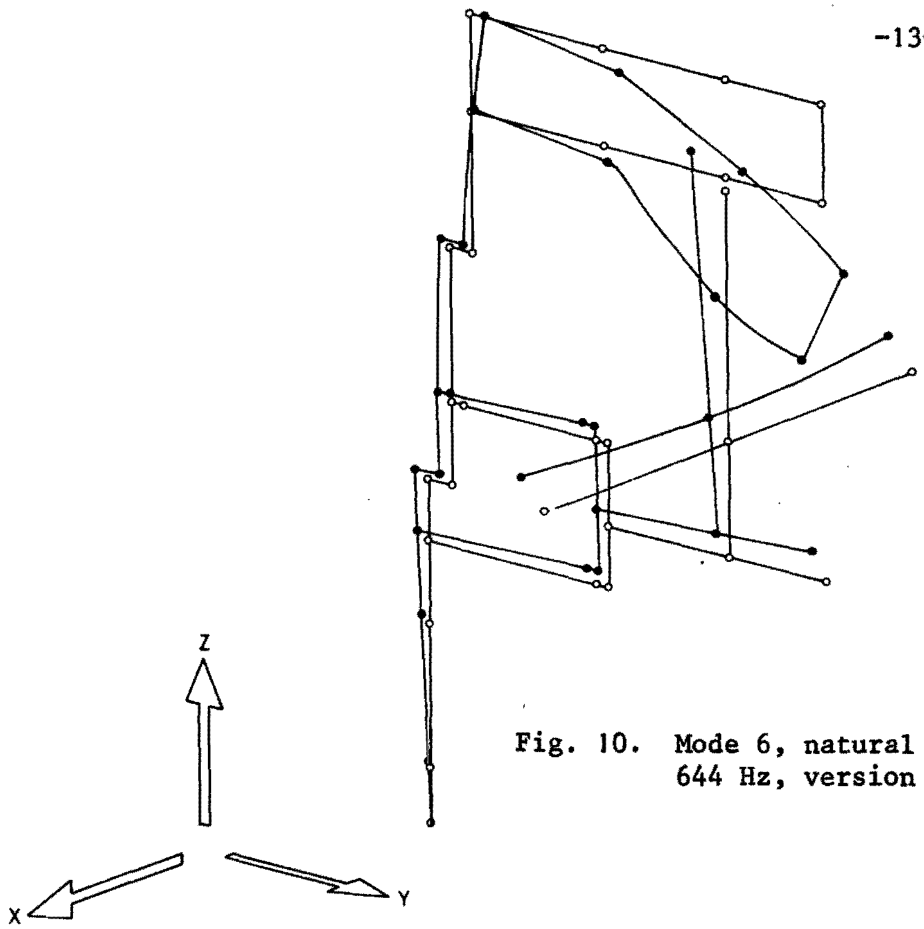


Fig. 10. Mode 6, natural frequency 644 Hz, version 2.

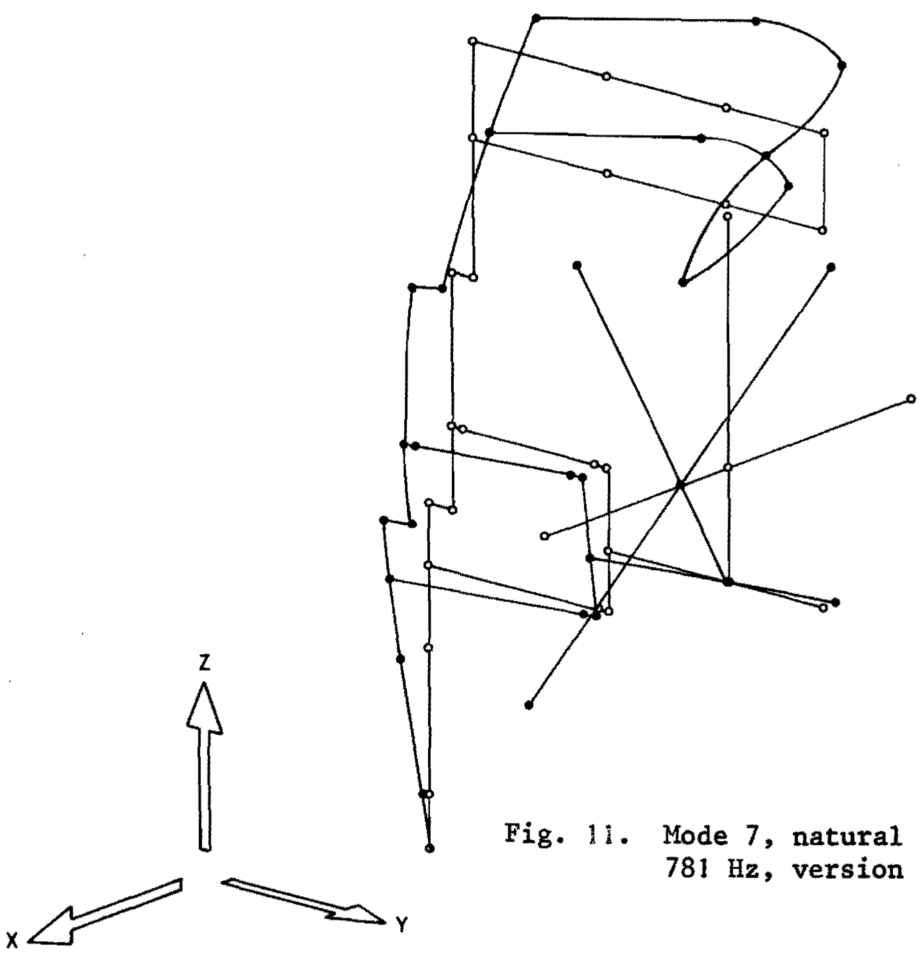


Fig. 11. Mode 7, natural frequency 781 Hz, version 2.

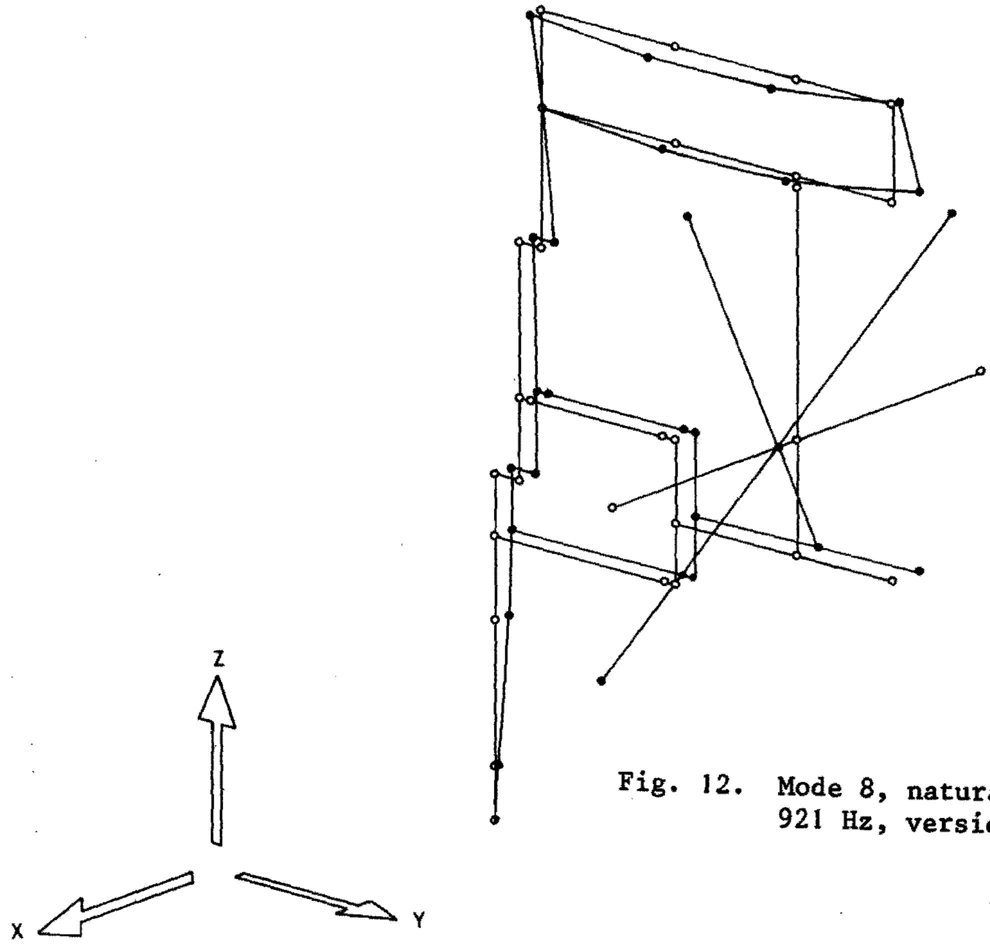


Fig. 12. Mode 8, natural frequency 921 Hz, version 2.

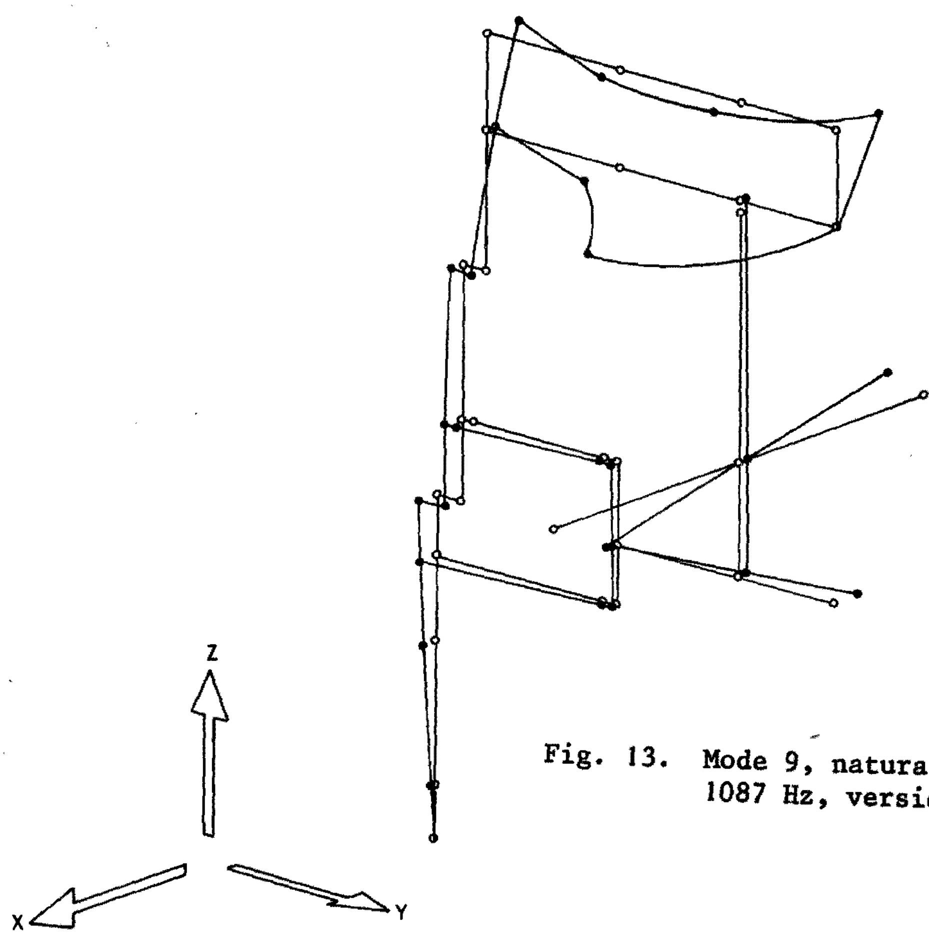


Fig. 13. Mode 9, natural frequency 1087 Hz, version 2.

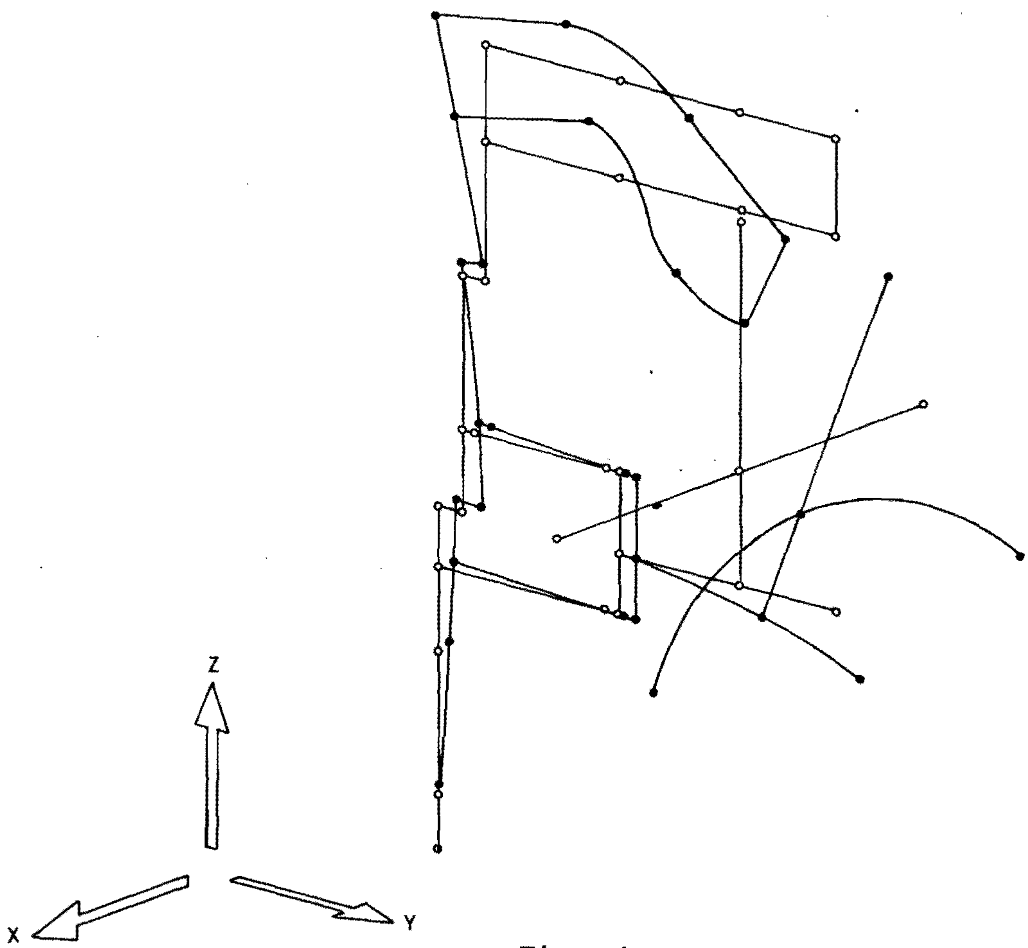


Fig. 14. Mode 10, natural frequency 1088 Hz, version 2.