Modal Analysis: A Dynamic Ski Test

Mr. Bob Rice[1]
Dr. Rand Decker[1]
Dr. Richard W. Shorthill[2]

Abstract

The dynamic behavior of skis is investigated using a digital spectrum analyzer and measuring both the input force and the response motion. The natural frequencies, damping and mode shapes are measured. Currently, ski tests are limited to static measurements such as, the bending or twisting of the ski in transverse directions with various fixed weights and measurements of moment of inertia. However, matching skis by their frequency response and damping values will provide a more accurately matched pair when combined with static measurements. In addition, our skis are tested dynamically after every ten days of use. By this method, the change in the dynamic response of the ski is tracked. This data provides information on the life of skis i.e., maximum performance and when it is time for a new pair. Skiers can establish an optimal profile for the kind of ski they like, to find that "perfect pair of skis". Modal analysis may provide a good test to establish whether a ski has been internally damaged, or as the ski manufacturers term "has gone flat". The dynamics of a damaged ski are significantly different from that of the undamaged one.

Introduction

Currently, we are examing the dynamic response or natural modes of vibrations for high technology skis. Using a digital spectrum analyzer and measuring both the input force function and response motion, the dynamic behavior of the ski is characterized by its natural frequencies. In the past, evaluation of skis have been limited to static measurements such as, the bending along the long axis of the ski with various fixed weights and measurements of moment of inertia. Along with these quantitative measurements, skis are also evaluated by testers on the ski slopes. Then the tester writes a subjective review of what they

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[1] Department of Civil Engineering, University of Utah, Salt Lake City, Utah 84112

[2] Department of Mechanical Engineering, University of Utah, Salt Lake City, Utah 84112

feel about the ski. The purpose of this project is to quantify many of the parameters found in the subjective tests and enhance the accuracy of the static measurements.

Ski modal analysis is not a new technology to the ski industry. Manufacturers use modal analysis in research and development. The manufacturers have identified three distinct vibration modes. The first effects the edge-holding capabilities. The second determines shock-absorbing characteristics. The third governs the overall stability. Manufacturers can selectively damp the ski by damping those vibrations that might hinder performance. Each mode will have a certain amount of damping, but will be completely damped out. The result of a complete damping process would result in a dead ski. Manufacturers use modal analysis to identify various modes of a ski and adjust them according to the ski design,Machine Design(1991). However, the ski manufacturer has not used or experimented with modal analysis in the same manner that we are experimenting.

Of interest to the ski manufacturers and retailers is the initial "match" between individual skis of a pair. A good pair should be well matched. Once a pair of skis has been put into service, novice and expert skiers are becoming increasingly aware that modern skis have a tendency to change over the service life of the skis. In addition it is common to damage the internal structure of the ski without causing any cosmetic damage. Ski racers will develop an intense like or dislike for a specific pair of skis with a given model line. All of these issues have at their root the dynamic response of the skis and the history of that response change. This research will quantify the dynamic response of the ski, map the history of changes in that dynamic response over the service life of the skis and quantify the change in the response between the damaged ski and its pair mate. Many of today's skis are made of the same materials that are finding increased use in aerospace, auto, and advanced building materials community,Canadian Consumer(1989). Very little is known about the changes that can be expected in these materials after thousands of cycles of finite strain levels. This research has the potential to lead to new findings in this area.

Methods and Procedures

The method used to determine a skis dynamic response is the application of modal analysis technique. To generate the collected data a computer modal analysis software is utilized. This software operates with a multi channel Fast Fourier Transform (FFT) analyzer. The programs run on a Hewlet Packard work station.

Initially we layout 31 points on a ski, ten on each edge, ten in the center and one on the tip, which are five inches apart, along the long axis of the ski. In these initial tests, points are placed between the midpoint and the tip of the ski.

Then the X-Y coordinates are determined and transferred to the computer. See Figure 1(undeformed structure). For these tests the ski is clamped between the toe and the heal piece. An accelerometer is progressively fixed to each test point on the ski. The ski is struck by an instrumented hammer at a designated point on the ski, separated from any node of the vibrating frequencies. The hammer consists of an integral quartz force sensor mounted on the striking end of the hammer head. The signals from the accelerometer sensor and the hammer are feed to the digital spectrum analyzer producing a transfer function and for analysis by the modal analysis software. Next a measurement is chosen that represents the thirty one test points. Then the various mode shapes are identified and marked by the software. The computer then goes through the remaining thirty points and collects the responses at the chosen modes. Finally the software displays the average frequency, percent of critical damping and the damping frequency of each mode for that particular ski being tested. Once this is completed the ski can be animated on the computer screen, showing each of the separate mode shapes. Figures 2 - 4 are the three mode shapes of a giant slalom ski.

After these initial tests, the skis are mounted with bindings, and returned to the lab for another set of tests. These sets of tests determine whether the mounting of bindings cause any change to the dynamic response of the ski. Then field tests are conducted. After every day of use, for the first ten days, the skis are returned to the lab for further tests. Once these first ten day test series are completed, the ski is brought back to the lab every tenth day. As these test progress a detailed map of each mode frequency change will be recorded. These changes will be used to quantify those natural frequencies and frequency change or shift which can be used to define maximum performance, and toward the end of the ski life, those frequencies that define a "flat ski".

Results and Discussion

Data was collected on seven pairs of skis and a basic analysis for the initial test conditions was completed. The data was collected on two pairs of handpicked or perfectly matched skis. These skis were handpicked and tested statically by a manufacturers technician. Also, two pairs of marginally matched skis were tested. The skis tested were giant slalom and slalom skis. Then three pairs of damaged skis were tested. These damaged skis had been returned to the manufacturer by skiers.

The initial objective is to determine whether modal analysis can detect any deviation in frequencies and frequency properties between an A-matched and C-matched pair of skis. The giant slalom and slalom skis were tested. The initial data received from modal analysis(see Table 1) indicates that a matching process is achieved. From this initial data, modal analysis indicates that the A-matched and C-matched pairs are closely matched. There is only a slight discrepancy between the frequencies. However, if the skis are crossed matched, the frequencies between the A-matched and C-matched are greatly different. There is over a ten percent difference between the left A-match and C-matched skis for the giant slalom and slalom skis. This is significant, because these skis came out of the same mold and manufacturing process. We tested only the forward half of the ski, the entire signature of the ski is incomplete. Once the test for the entire ski is initiated the complete dynamic signature of the ski will be defined. It is interesting to note, that the manufacturers have damped out the entire first mode of the giant slalom ski, to gain more control at high speeds, and provide greater edge control.

Modal analysis was performed on the damaged pairs of skis. The first pair tested was a giant slalom ski with a bent tip.The frequency changes between the right and let ski are negligible(see Table 2).The initial assumption assumed that the bent ski would display different characteristics than its matched pair, due to the material degradation. In Table 2 we observe that the frequencies only shift about one percent between the right and left ski. The damaged giant slalom ski is still defined by frequencies compatible with the three modes which define the A-matched giant slalom ski. The final two tests on the damaged slalom skis(Table 2) indicate no changes between the right and left skis. These tests on the damaged slalom skis are in line with the manufacturers tests and opinion that the skis are not damaged.

Conclusion

Since these test began in the spring of 1994, data on the aging process is incomplete. As the winter of 1994-1995 progresses, data from the field tests will become available. We expect that these tests will provide data useful to the manufacturer and retailer. As these tests indicate, Modal Analysis can provide information on the aging process of skis, the initial match between skis and damage to the ski.

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Frequency Table 1

Giant Slalom A-Match:

	LEFT	RIGHT	
Mode	FREQ(Hz)	FREQ(Hz)	% Change
1	0.000	0.000	0.000%
2	38.861	38.555	0.787%
3	92.088	91.378	0.771%
4	171.837	170.803	0.602%

Giant Slalom C-Match:

Mode	FREQ(Hz)	FREQ(Hz)	% Change
1	0.000	0.000	0.000%
2	38.322	38.398	0.198%
3	90.842	91.147	0.335%
4	169.706	170.672	0.566%

Slalom A-Match:

Mode	FREQ(Hz)	FREQ(Hz)	% Change
1	10.880	10.637	2.23%
2	40.806	40.673	0.326%
3	99.104	98.289	0.822%
4	188.549	183.957	2.44%

Slalom C-Match:

Mode	FREQ(Hz)	FREQ(Hz)	% Change
1	9.796	9.910	1.15%
2	38.322	38.398	0.198%
3	90.842	91.147	0.335%
4	169.706	170.672	0.566%

Frequency Table 2

Giant Slalom Broken:

Mode	LEFT FREQ(Hz)	RIGHT FREQ(Hz)	% Change
0	0.000	0.000	0.00%
2	38.644	38.146	1.28%
3	92.609	91.703	0.978%
4	171.536	171.020	0.301%

Slalom Broken(188cm):

Mode	FREQ(Hz)	FREQ(Hz)	% Change
1	10.575	10.601	0.245%
2	39.408	39.959	1.38%
3	97.138	98.679	1.56%
4	177.748	180.353	1.44%

Slalom Broken(201cm):

Mode	FREQ(Hz)	FREQ(Hz)	% Change
1	10.337	10.505	1.60%
2	38.243	38.824	1.50%
3	93.348	94.465	1.18%
4	173.443	177.687	2.39%

Figure 1

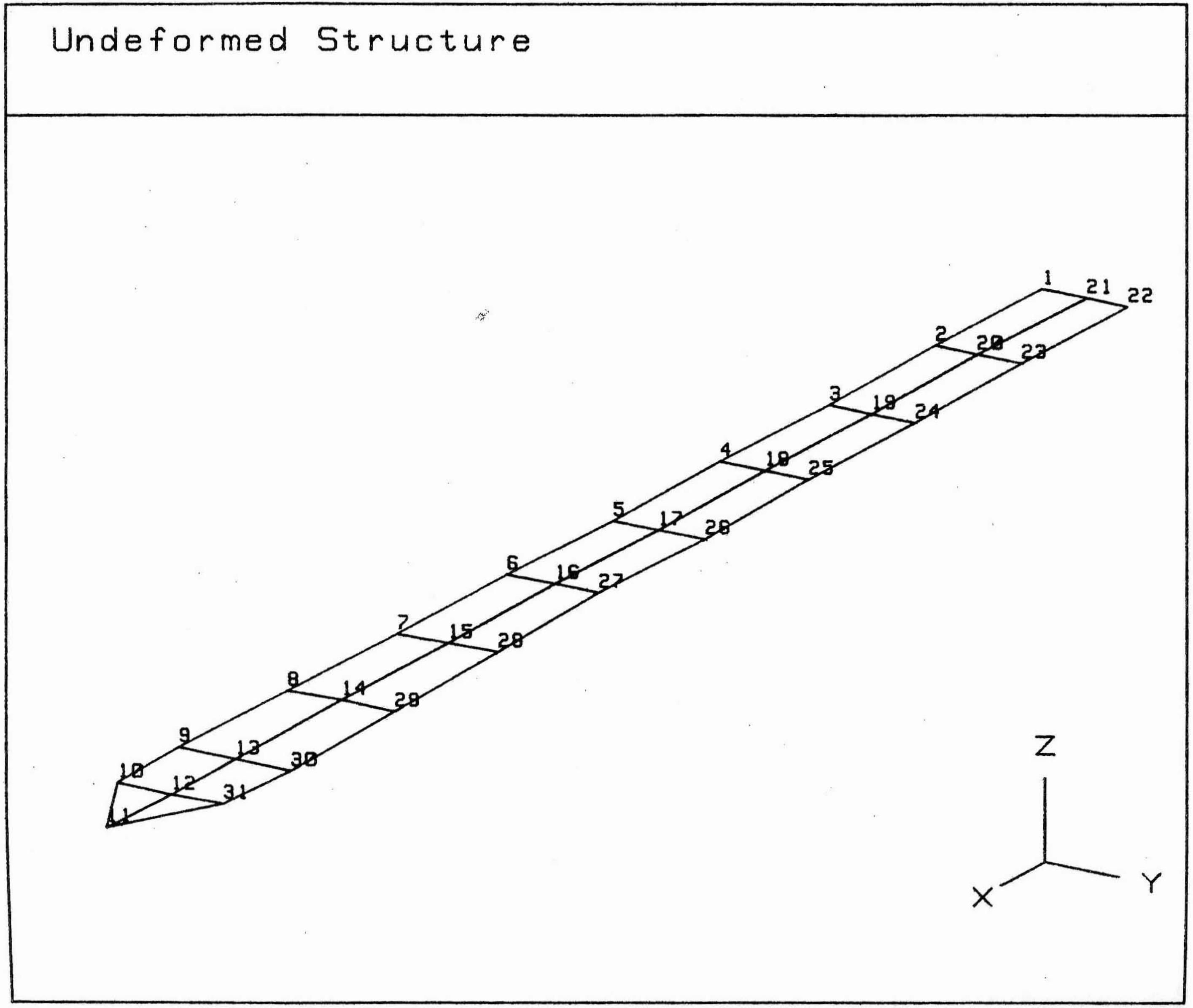
Undeformed Structure
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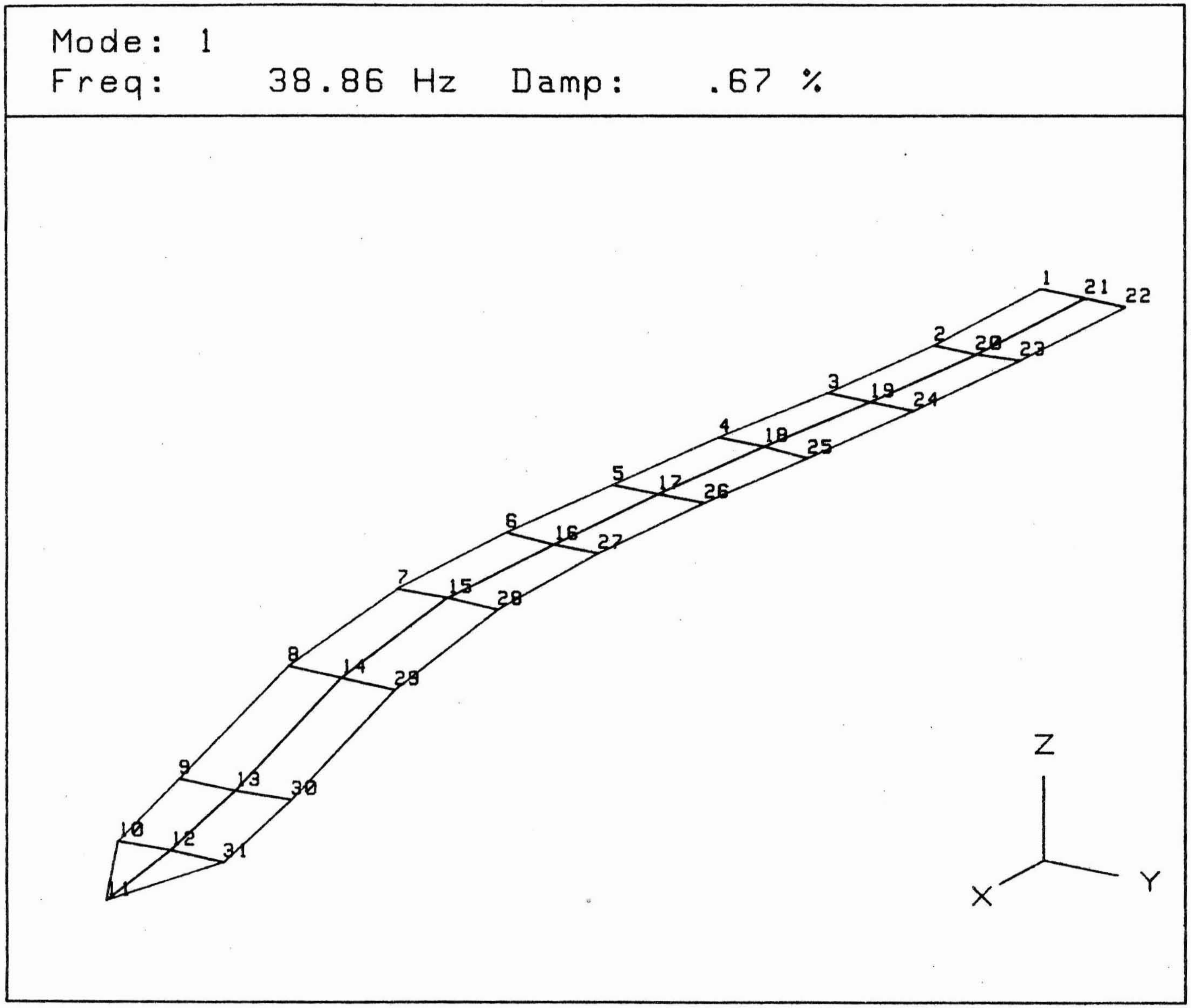
Figure 2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Freq: 38.86 Hz Damp: .67 %
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Figure 3

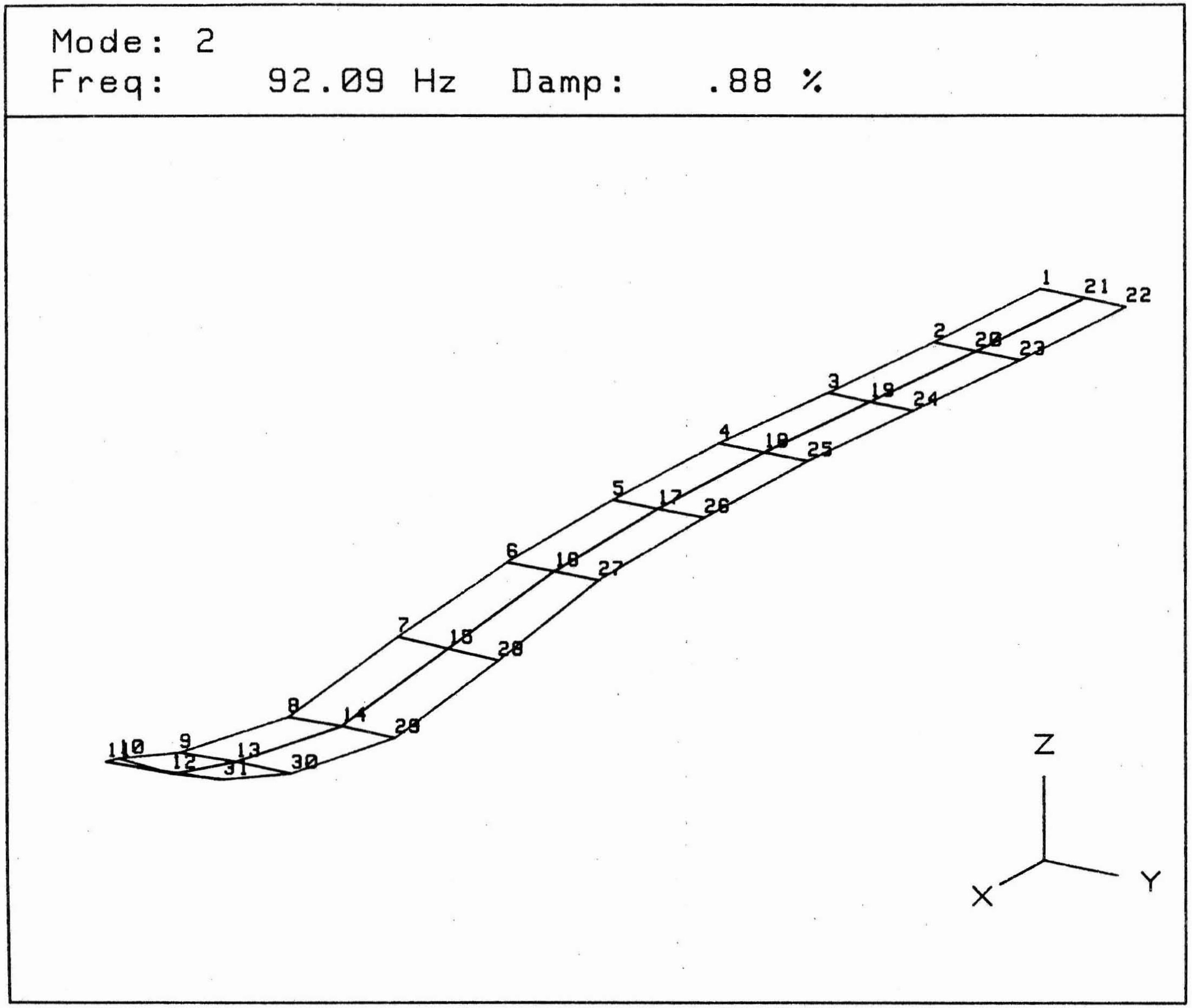
Mode: 2
Freq: 92.09 Hz Damp: .88 %
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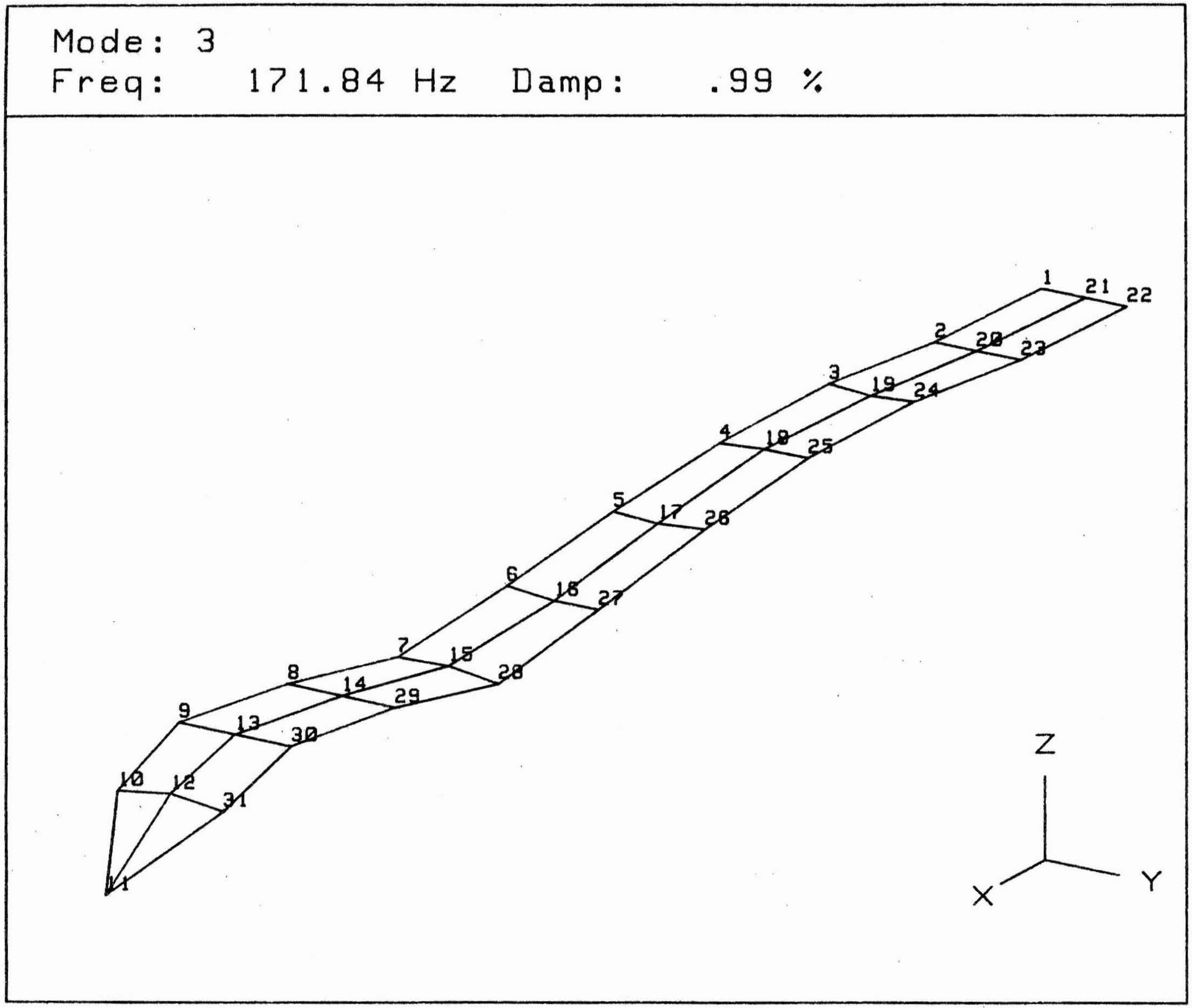
Figure 4



Mode: 3
Freq: 171.84 Hz Damp: .99 %