OUT-OF-PLANE DYNAMICS OF WEB AT AN AIR REVERSER

By

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1997

Submitted to the Faculty of the Graduate College of
the Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
May 2002

OUT-OF-PLANE DYNAMICS OF WEB

AT AN AIR REVERSER

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ACKNOWLEDGEMENTS

I deeply express my gratitude and respect to my advisor, Dr. P. M. Moretti, without whose guidance and encouragement I would never have been able to do my research work. I would like to thank Dr. Lu and Dr. Young for their acceptance to be on my committee and for their encouragement and suggestions.

I would like to thank all research assistants working in WHRC for creating a pleasant working atmosphere. I appreciate the sponsors of WHRC and Oklahoma State University for the support they provided to do my research work.

Finally I would like to thank my parents, brothers and sister, whose love and encouragement supported me at every point during my study.

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NOMENCLATURE

2β	Total Wrap Angle
2α	Porous-Region Angle
θ	Over-Wrap Angle (β-α)
T	Tension (lbs/in.)
p	Pressure (Inches of Water)
d	Diameter of Air-Turn Bar

CHAPTER 1

INTRODUCTION

1.1 Background

A web can be defined as a continuous thin material, such as paper, plastic sheet, magnetic media, or polymer film. Before being converted into the final product, the web passes through various processes, such as printing, drying, coating, or lamination. Air bars support the moving web during drying of coated or printed polymers, as the coated side of the web should not be touched before drying. This process of drying combined with aerodynamic support is called web flotation drying, where in air jets support the moving web, without any mechanical contact, and dry the coated surface of the web. In flotation drying the heated air can be directed from the bottom, top, or both sides of the web. The devices with air nozzles supporting the moving web are called air bars.

An air-turn bar is another kind of web supporting device. Air turn bars are mainly used to change the direction of the moving web, in addition to avoiding web contact and providing uniform and controlled heat and mass transfer. A schematic diagram of a web over an air turn bar is shown in figure 1.1.

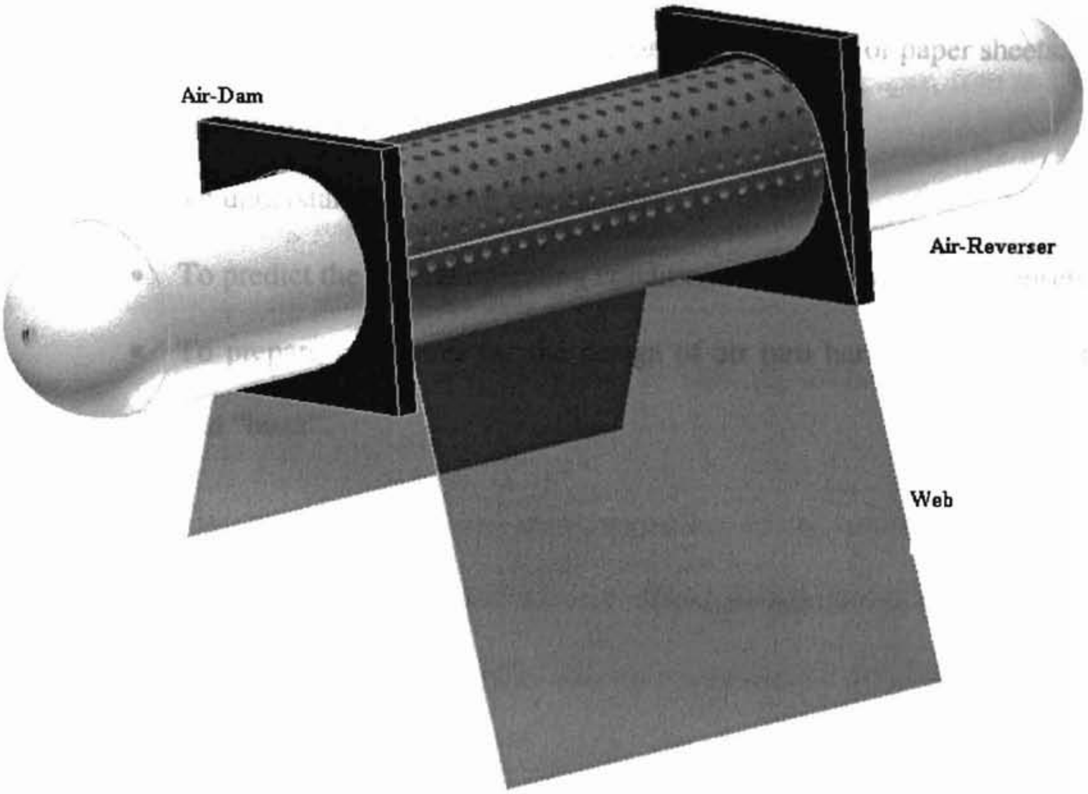


Figure 1.1 Schematic Diagram of Air Turn Bar

1.2 Research Objectives

Different types of instability problems such as web flutter, buzzing sounds and lateral instability are encountered with the use of air bars. These problems are difficult to predict and are handled by trial and error. Web flutter is a serious obstacle to high-speed operation of the web machine and air-flotation drying of the web materials. It can lead to breakdowns in paper machines, and damage the coating on polymer or paper sheets.

The purpose of this study is:

- To understand the flutter mechanisms.
- To predict the critical operating conditions at which web flutter onsets.
- To prepare guidelines for the design of air turn bars to avoid the flutter and "buzz".

CHAPTER 2

LITERATURE REVIEW

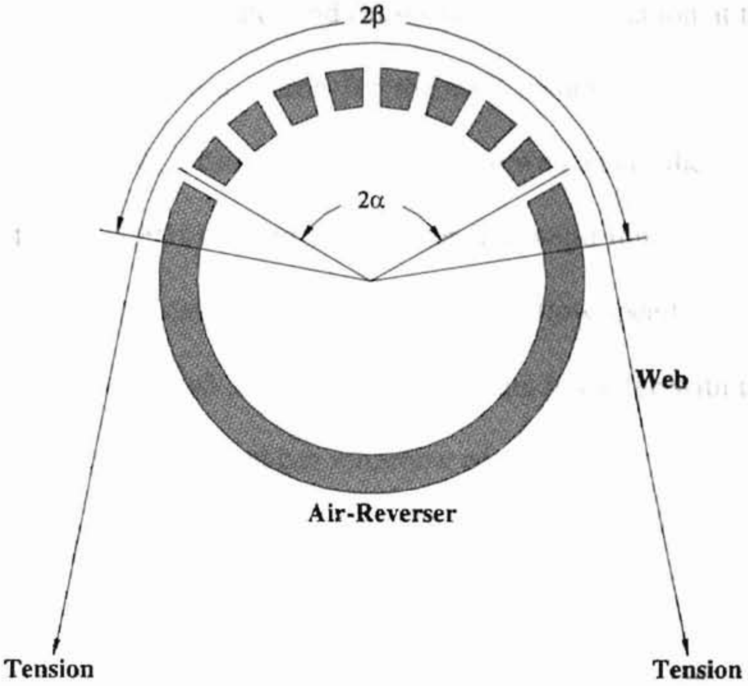
Flotation devices are widely used in web industries such as paper, film and fabric webs. Fraser (1983) described some of the useful web supporting devices. He described two types of air turning bars, one with slots and the other with holes. The two major problems associated with such air turn bars are:

1. Excessive loss of air from the slots or rows of holes uncovered by the web.
2. Air loss from the edges of the web.

Mounting side plates and adjusting them according to the width of the web can minimize the air loss from the edges of the web. Improper adjustment of the plates can result in an additional problem of web edge damage. A schematic drawing of the air turn bar and the web is shown in Figure 2.1.

Several papers have described hydrodynamic instability of the web. Some of them are discussed in this chapter.

Inada and Hayama (1988) discussed flow-induced vibrations in a one-dimensional narrow passage in which one of the walls is vibrating. They first analyzed the flow-induced forces acting on the walls of the tapered passage. Secondly, flow-induced forces were calculated for the arbitrary passage using the transfer matrix method. It has been found that both negative fluid-dynamic stiffness and damping can occur in the tapered passage if the cross-sectional area of the downstream passage is larger than the upstream one. This can be one of the reasons for the web instability at the air-reverser.



2β: Total Wrap Angle

2α: Porous-Region Angle

Over-Wrap angle $\theta = \beta - \alpha$

Figure 2.1 Schematic Diagram of Over-Wrapped Web

According to Segawa (1993), a flexible web forming a parallel or tapered channel with a rigid wall can experience instability due to the airflow through the gap between the web and the wall. He analyzed the destabilizing effect of the rigid wall on the elastic plate placed in the path of the uniform irrotational fluid flow adjoining the rigid flat wall, using linear potential-flow theory. It was found that instability was sensitive to the inclination angle and the gap between the web and the rigid wall.

In diverging channel fluid flow, the airflow may separate from either of the boundaries. According to Moretti (1990), in many cases the flow stream separates from either side, and in other cases it oscillates and causes pressure fluctuation at the boundary layer. The same condition can be a reason for the web instability at the air-reverser, because we get the same kind of airflow at the point where web leaves the air-reverser.

Chang and Moretti (1991a), tested edge flutter in a wind tunnel using stationary webs. The free edge of the web started to vibrate at a critical flow speed and its amplitude grew drastically with the flow speed. Local interaction of the free edge with the airflow is critical. Reducing the flow near the edge can minimize edge flutter.

Sundrarajan (1966), assumed that the air on the top of the web is still. The flow between the web and the wall is considered two-dimensional, incompressible and subsonic. Sundrarajan's flow model is similar to Segawa's except that the flow velocity and the fluid density of the antiwall side were assumed to be zero.

Watanabe, Suzuki, Sueoka and Kunimaru (1991) described the flutter mechanism of the web sheet. Sheet flutter is caused by the pressure fluctuation due to the vortex released from the downstream edge. The flutter frequency increases in proportion to the air speed.

David (1996) suggested some reasons for the web instability. According to David web instability can be caused by:

1. Web slack on one side due to roller misalignment or cantilever roller deflection.
2. Tension oscillation.
3. Air currents from external source, especially at the edge of the long span.

One universal means of reducing the web flutter is to increase the web tension. In most cases, the web should be tensioned to at least 10 percent of its strength. Increasing web tension beyond 10 percent may cause web breaks.

Web wrapped beyond the last row of holes is called over-wrapped web and the angle between this web and the line tangent to the last row of holes is called over-wrap angle, as shown in the Figure 2.1.

Over-wrap Angle $\theta = (\beta - \alpha)$

Web, which is not fully covering the holes, has negative over-wrap (i.e. under-wrapped web angle, is shown in figure 2.2.

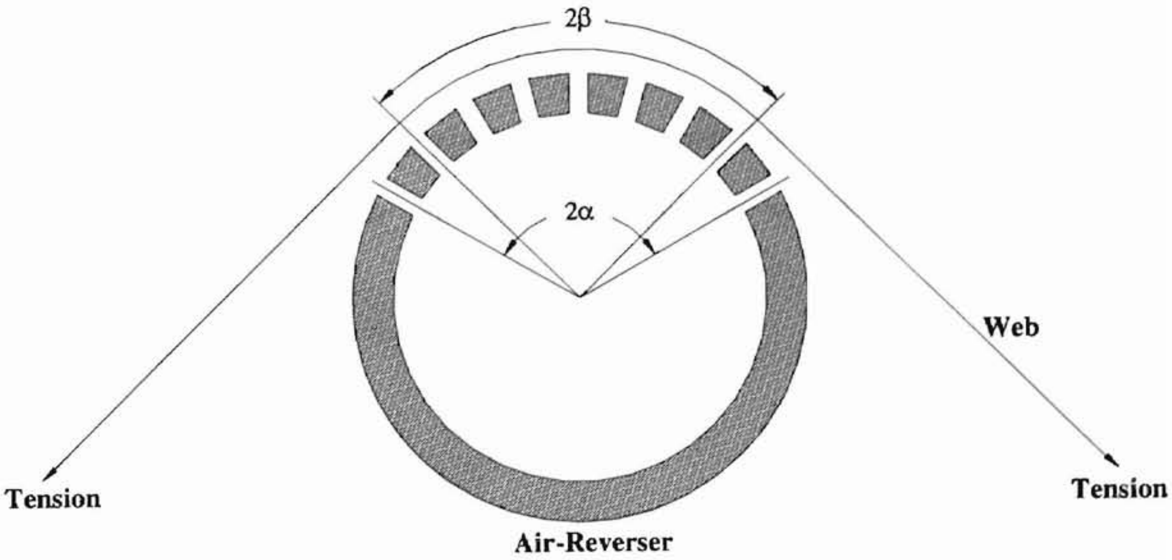


Figure 2.2 Schematic Diagram Under-Wrapped Web

CHAPTER 3

REVIEW OF PREVIOUS WORK ON OUT-OF-STATE INSTABILITY

3.1 Out-of-Plane Instabilities at Air-Turn Bar

Zeelani (1994) used two types of air-turn bars in his experiments, as shown in figures 3.1 and 3.2. Both of the air-turn bars were 2 inches in diameter, and a 6 inches wide web was used on them. Air-turn bar, shown in figure 3.1, had two rows of holes and other one, shown in figure 3.2, had several holes. Rotation of the bars changed the wrap-angle on the active side. For simplicity the web was mounted asymmetrically on the air-reverser as shown in the figure 3.3

Five types of instability phenomena, including three dynamic instabilities, were observed under varying air pressure supply, tension and wrap angle in Zeelani's experiments.

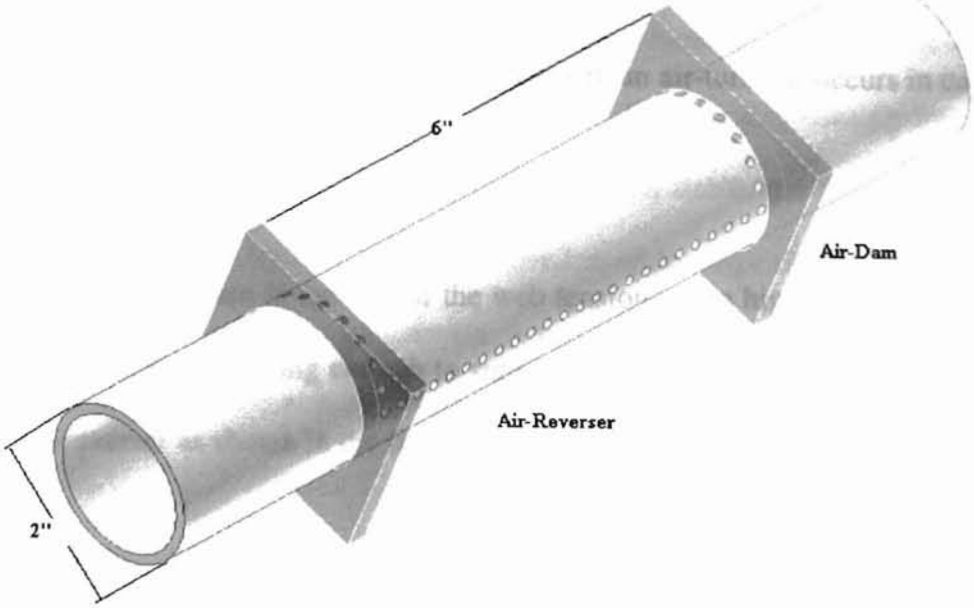


Figure 3.1 Air-Turn Bar with two rows of holes

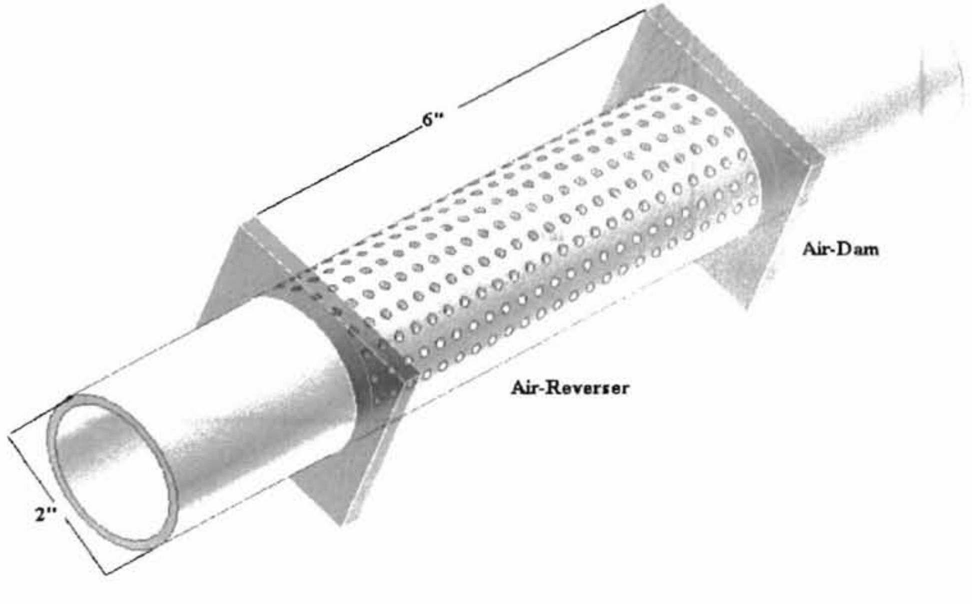


Figure 3.2 Air-Turn Bar with array of holes

3.1.1 Touching of the Web at Air-Reverser

Static instability, or touching of the web with an air-turn bar occurs in cases of:

1. Low air-pressure
2. High web tension.

If the air pressure is too low or the web tension is too high, the air-jet supporting the web will not be strong enough to support the web. This will make the web touch the air-reverser as shown in the figure 3.3.

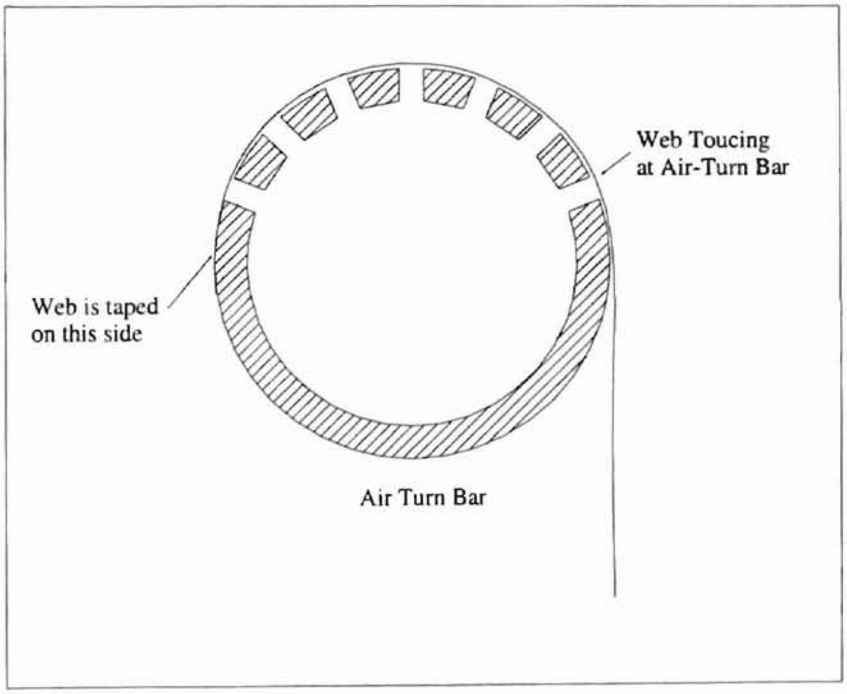


Figure 3.3 Web Touching at an Air-Turn Bar

3.1.2 Free-Span Flutter

At some operating conditions, the web span between the air-reverser and the adjacent support vibrates heavily at its fundamental frequency, causing loud noise or "buzz". The floating central region of the web remains stable and there is no change in the height, as shown in figure 3.4. This occurred at wide range of wrap angles. There is an increase in the web flutter with decrease in the wrap angle. The Gap between the web and the side plates can affect the web vibration mode. This will be further discussed in a later section.

This kind of instability could be the result of one or more of these reasons:

1. Parallel channel flow.
2. Diverging channel flow.
3. Wall jet formation.

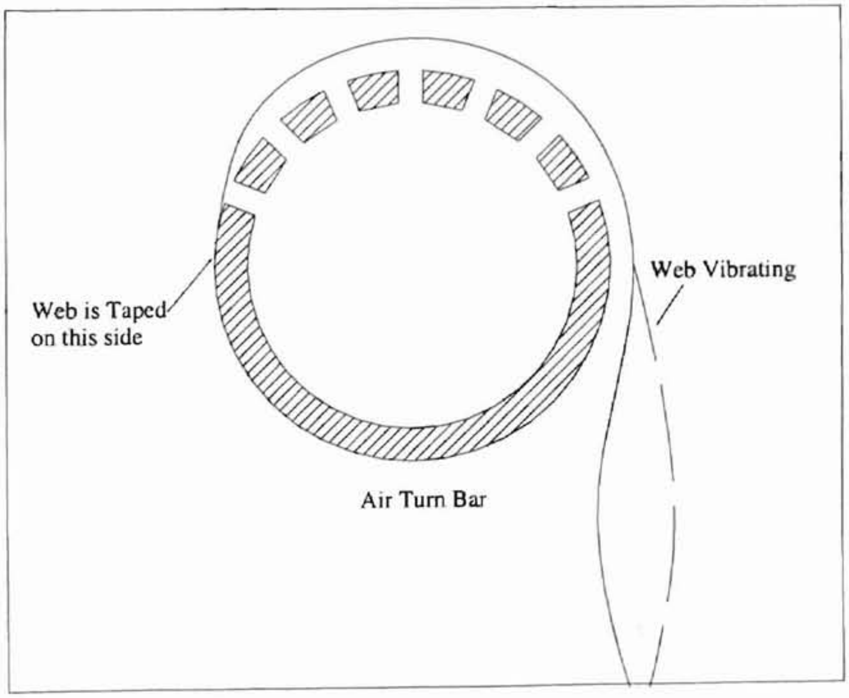


Figure 3.4 Free-Span Flutter

3.1.3 Bumping of the Web (Out-of-Phase Flutter)

Bumping is shown in the figure 3.5. The web was found bumping at the air-turn bar when the outer row of holes was located near the tangential-span-separation line. The web span between the air-reverser and the adjacent support vibrates out-of-phase with the part of the web wrapping the air-reverser. There is a significant effect of the air jet near the tangential line in this kind of instability. The gap between the web and the air-reverser fluctuates with constant frequency.

Bumping can be avoided by keeping the outer row of holes away from the tangential line. There is also some suppression in bumping with increase in the web tension.

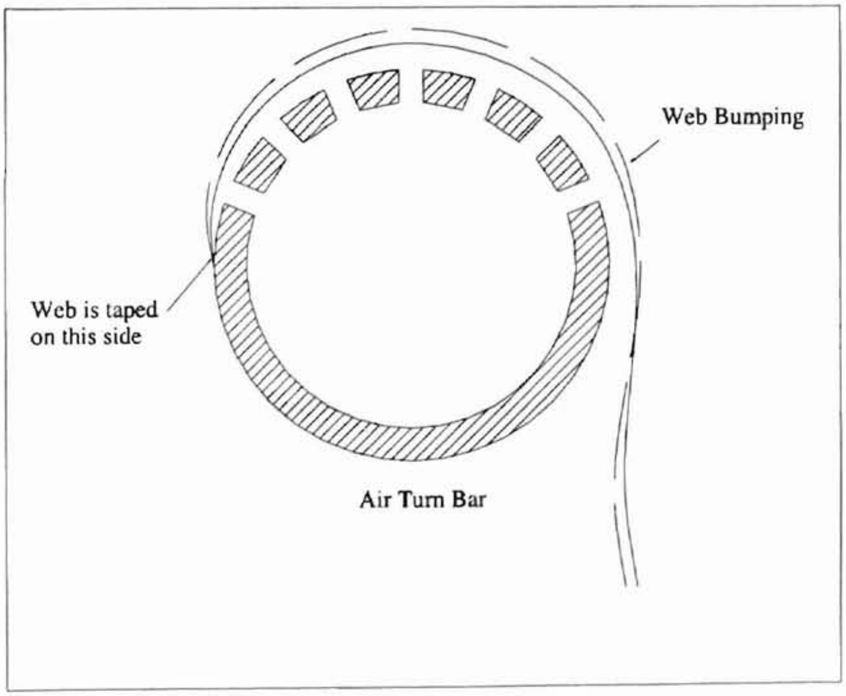


Figure 3.5 Bumping of the Web (Out-of-Phase Flutter)

3.1.3 In-Phase Flutter

In-phase flutter occurs in some operating conditions is shown in figure 3.6. In this type of instability, the web appears to be floating, but the part of it covering the air-turn-bar is actually vibrating with small amplitudes

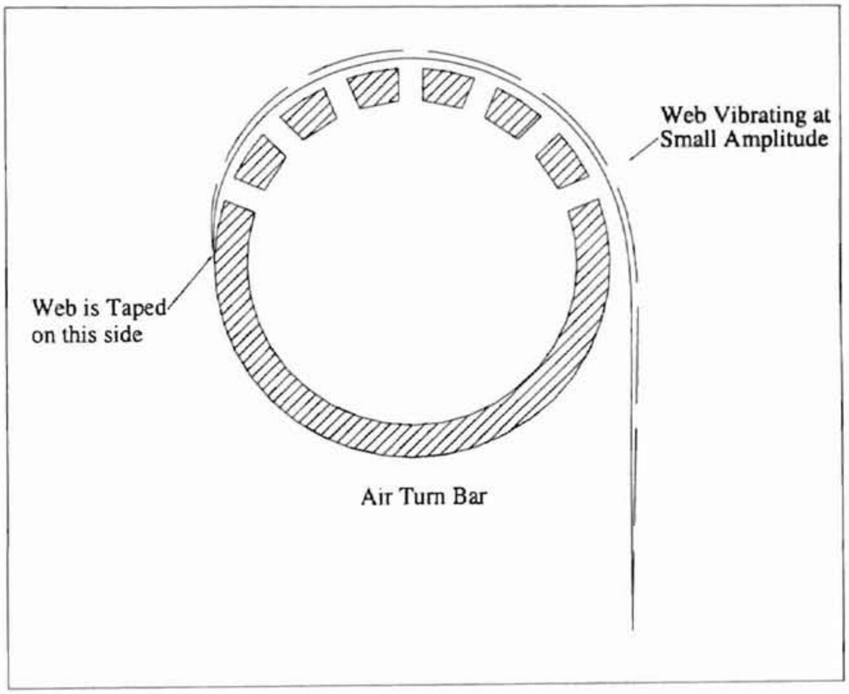


Figure 3.6 In-phase flutter

3.1.4 Bulging of the Web

This kind of instability, according to Zeelani, occurs when there is either a low web tension or a high supply pressure. There is no vibration in this instability. When the supply pressure is high and the web tension is low then the pressure between the web and the air-turn bar gap is high and the tension-induced pressure is less. This condition causes the bulging of the web as shown in figure 3.7

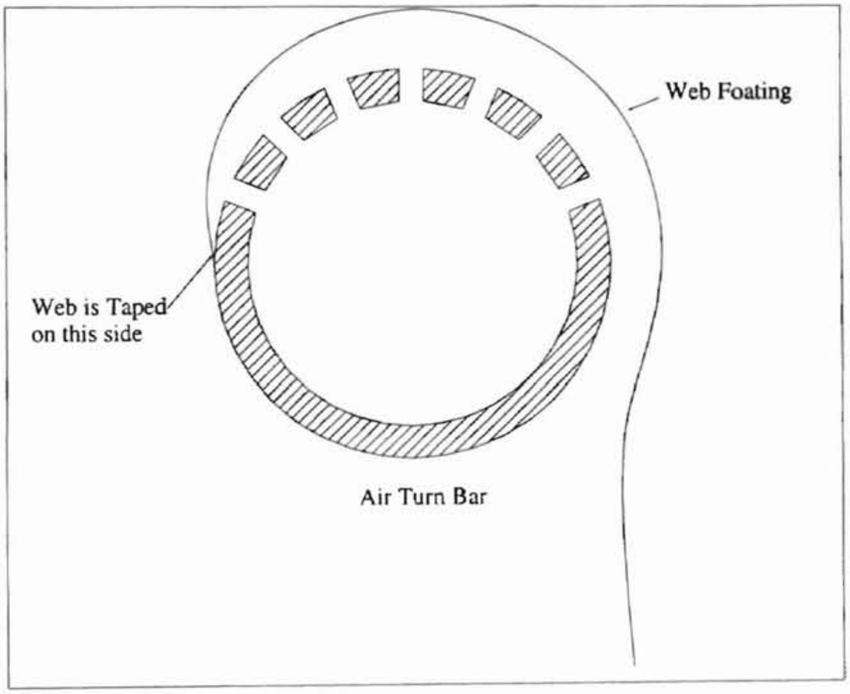


Figure 3.7 Bulging of the web

Zeelani used two maps to illustrate the conditions where the four instabilities are occurring. Except for touching, all of the instabilities phenomenon's described previously were plotted.

Graph, drawn between T/Pd (dimensionless value) and over-wrap angle, shown in Figure 3.8, shows the effect of over-wrap angle and web tension on in-phase flutter for air-turn bar with two rows of holes. It shows that in-phase flutter is decreasing with increase in the T/pd ratio. At over-wrap angle of 40°, bumping of the web starts. At this over-wrap angle there is low in-phase flutter up to 20 T/pd value and then bumping starts, which continues up to 77 T/pd value. Above this value of T/pd, the web seems to be floating freely without touching the air-reverser. When T/pd value reaches 250, the web experiences touching. Bumping of the web was seen in the range of –15° to 40° of over-wrap angle. For –15° and lower over-over wrap angles, web starts with floating and then in-phase flutter takes over floating, which continues till the web starts touching the air-reverser.

Figure 3.9 shows the effect of over-wrap angle and web tension on in-phase flutter for an air-turn bar with a dense array of holes. The same results as above were obtained with this air-turn bar.

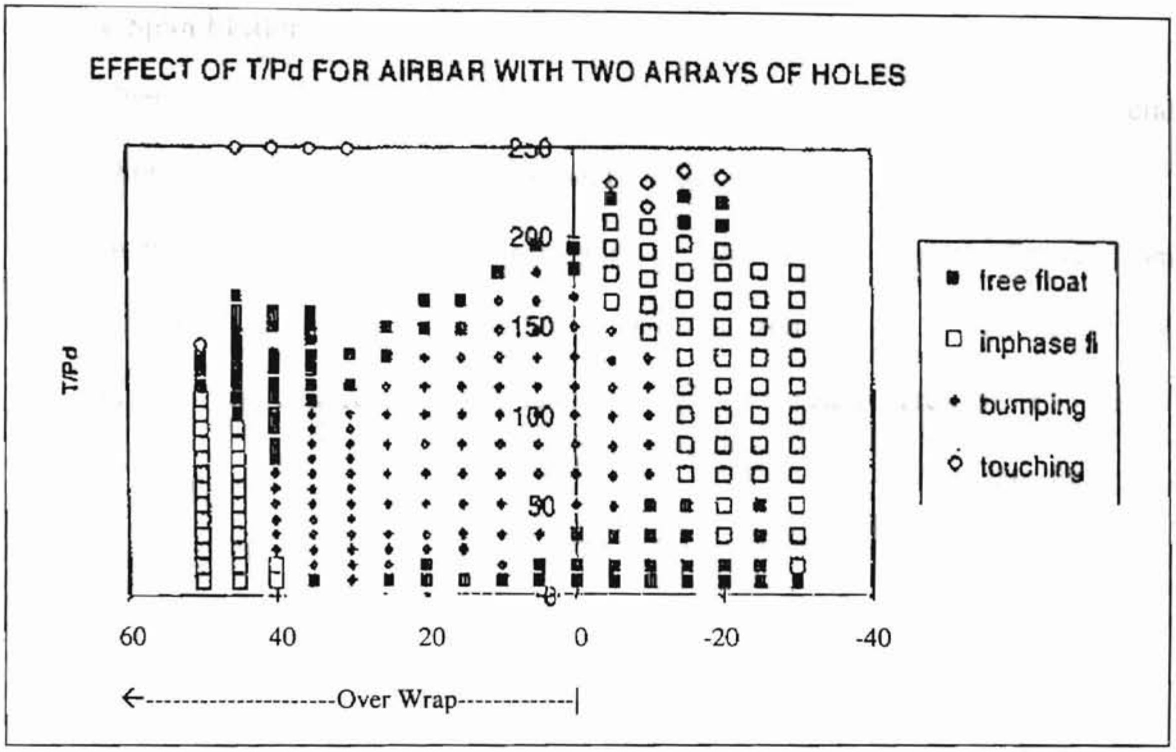
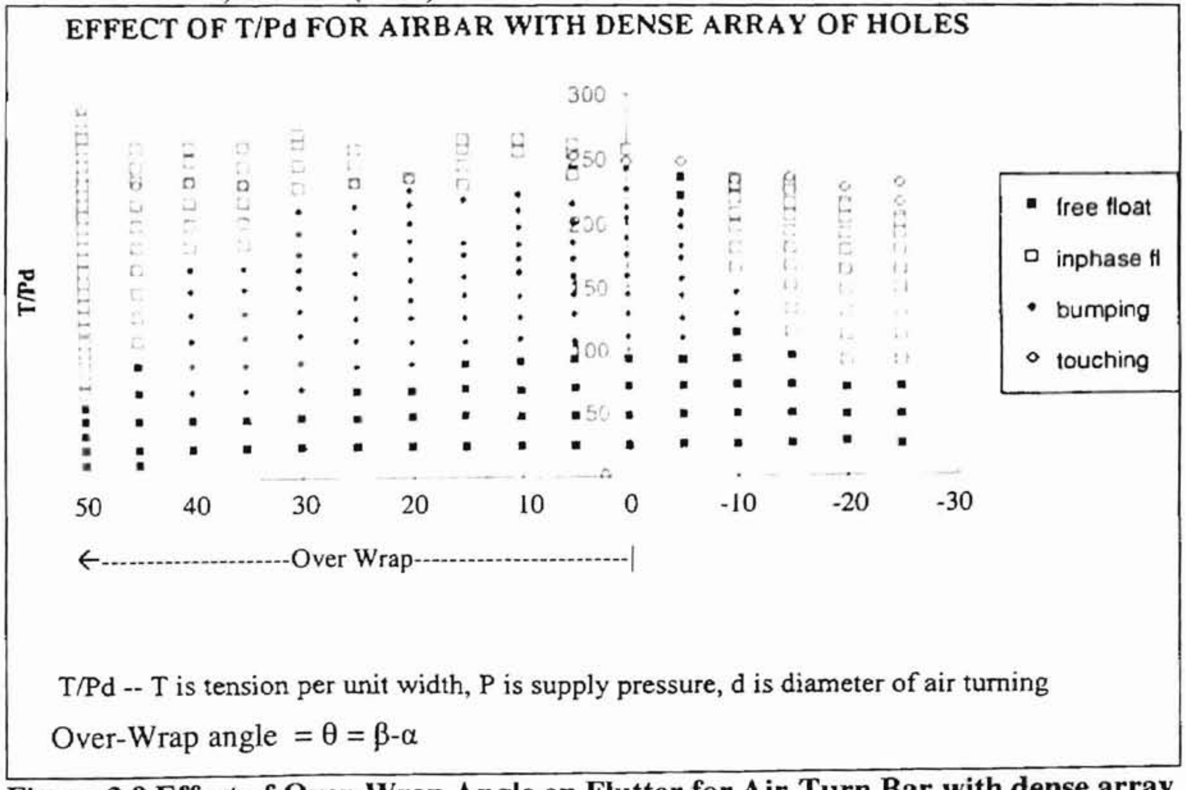


Figure 3.8 Effect of Over-Wrap Angle on Flutter for Air-Turn bar with two rows of holes, Zeelani (1994)



T/Pd -- T is tension per unit width, P is supply pressure, d is diameter of air turning

Over-Wrap angle $= \theta = \beta - \alpha$

Figure 3.9 Effect of Over-Wrap Angle on Flutter for Air-Turn Bar with dense array of holes, Zeelani (1994)

3.2 Free-Span Flutter

Chen (1996) investigated the free-span flutter, using the air-turn bar with several rows of holes in her experiments. Experimental setup of the web and the air-turn bar is shown in figure 3.10. One side of the air-turn bar was connected to the blower from vacuum cleaner with a maximum capacity of 580cfm at zero pressure. The other side of the air-turn bar was connected to the manometer, which measured pressure in inches of water. One end of the web was sealed to the air-turn bar. Moving the steel bar supporting the web at the other end varied the web span. Rotation of the air-turn bar changed wrap angle. Two laser Doppler vibrometers were used to measure the web flutter along the web. One of the vibrometer locations was at the middle of the span and other vibrometer was moved along the web to see the phase shift of the wave.

The web span between the air-turn bar and the adjacent support vibrated at different modes. Usually the instability was accompanied with loud noise, which increased with increase in the web tension. This phenomenon was observed at wide range of over-wrap angles.

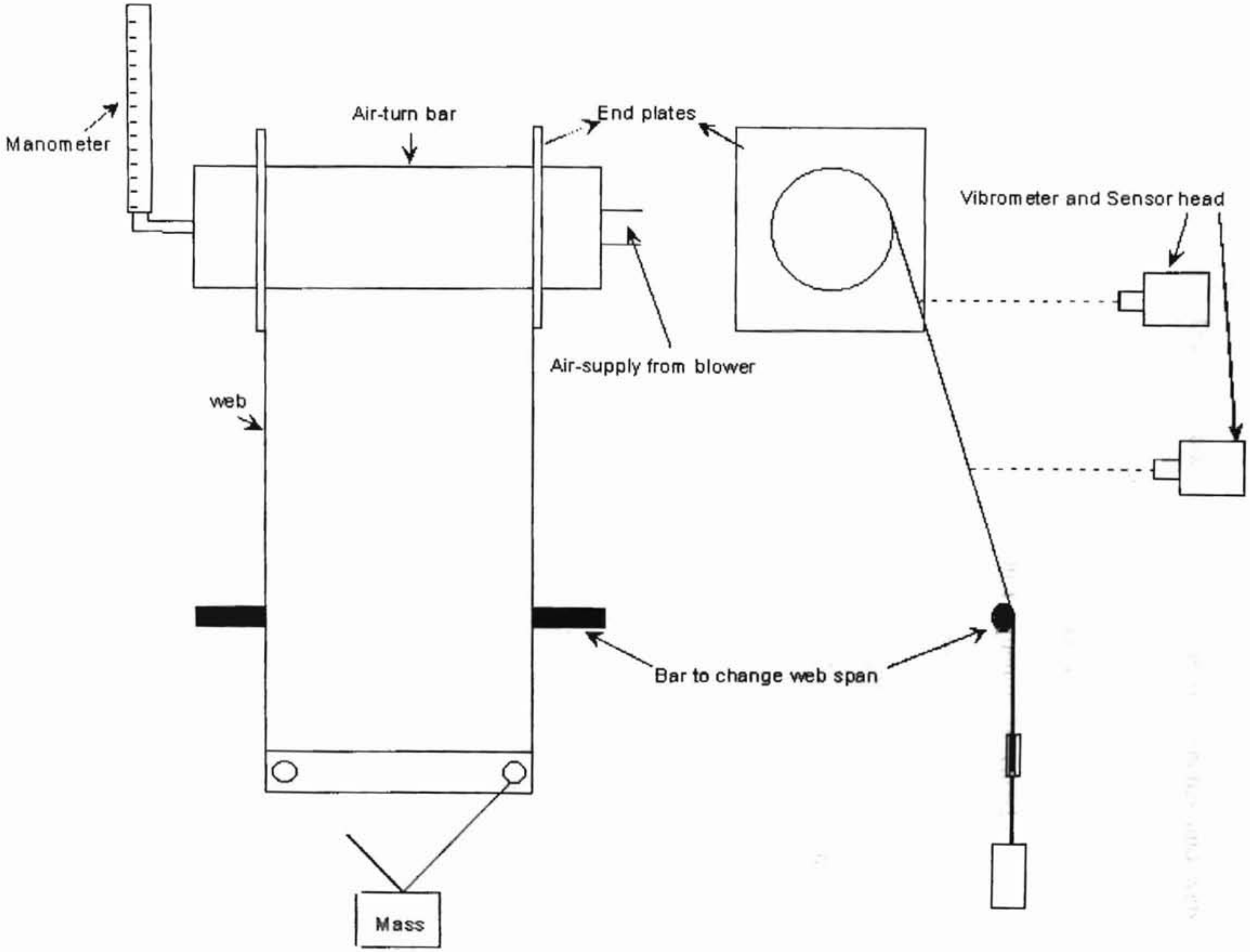


Figure 3.10 Schematic of Web and Air –Turn Bar Setup, Chen (1996)

3.2.1 Free-Span Flutter with no Edge Air Leakage

It had been assumed that there is no edge air leakage, as there is no significant effect of it on the measurements. Data was taken with web span of 7 inches and web width of 6 inches. Frequency was always increasing with increase in the web tension regardless of the web span and the over-wrap angle. Usually, the instability was accompanied with a loud buzzing noise. The fundamental frequency increased with the increase in web tension; surprisingly it also increased with increase in the web span. From the figure 3.11, it's obvious that the fundamental frequency is dominating the flutter for the entire range of web tension, although the second mode is showing its effects in the lower values of tension, and the third mode in the higher web tension. Fundamental frequency increases smoothly with web tension. The same results were obtained with different web spans. It had been found that frequency increased more rapidly for shorter web spans. Over-wrap angle also affected the increasing rate. Usually, the higher the over-wrap angle, the smoother the curve. However the difference was not that obvious. The over-wrap angle between 2° to 12° resulted in the maximum amount of amplitude.

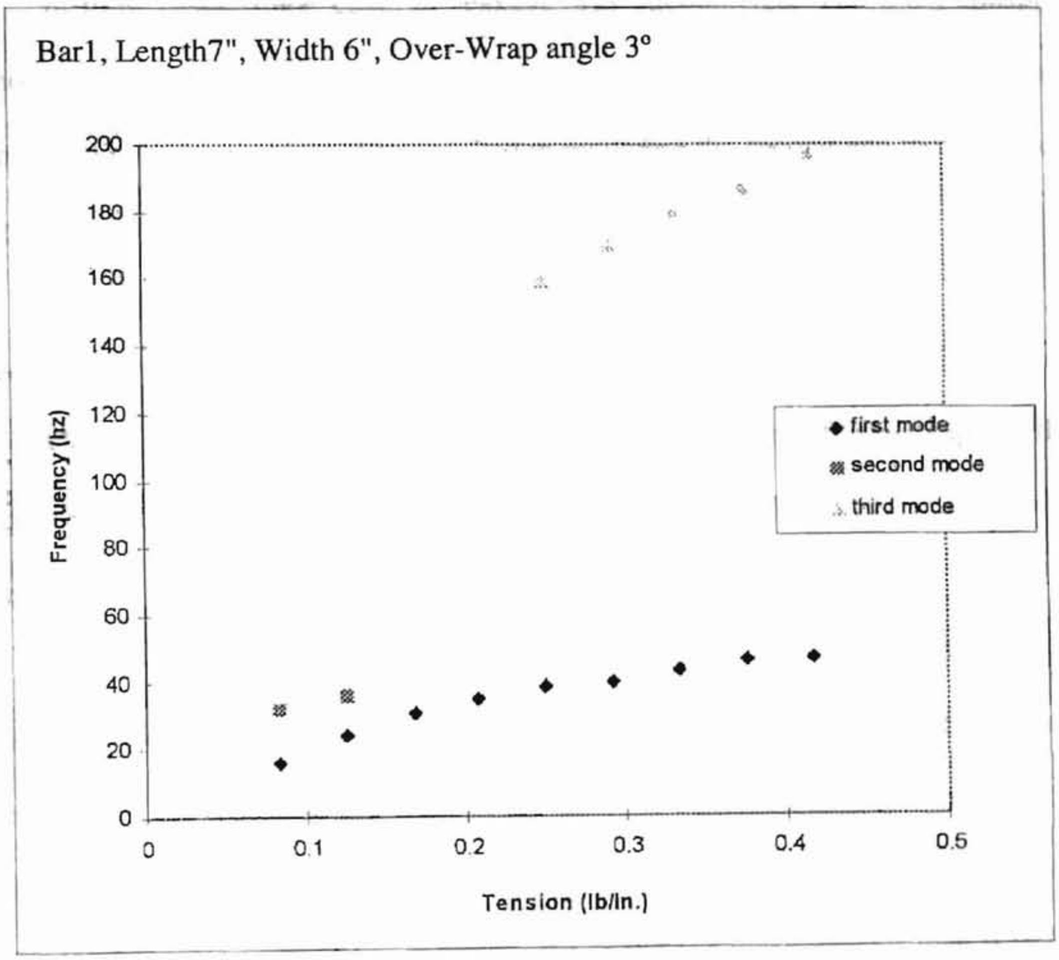


Figure 3.11 Effect of Web Tension on Flutter Frequency, Chen (1996)

3.2.2 Free-span Flutter with Edge Air Leakage

In most cases, some edge air leakage was encountered. The most conspicuous phenomenon encountered in this situation was that the fundamental frequency was very strong at all over-wrap angles. This resulted in rendering the second and third frequencies insignificant.

Effect of Edge Gap

Chen (1996) did some experiments to find the effect of edge gap on the air leakage. Significant differences in the flutter resulted as a result of gaps with and without air leakage.

When the gap is greater than 0.1", there is no change in the frequency and vibration mode. But when the gap is less than 0.1", the frequency is different and the mode is unstable. When the gap is less than .05", the condition is very similar to that of no air leakage. The gap leakage effect was also tested for the web span of 9.5". When the gap is .1", the web buzzes at low tensions. When the tension is greater than 0.167 lb/in, web stabilizes at 3 nodes mode. There is no effect of over-wrap angle on the stability of the flutter.

Effect of Over-Wrap angle

Over-wrap angle is an important factor for gaps lower than .05" (see table 3.1). For pressure 6.95" and web tension 0.125 lb/in, 3 nodes were obtained at 2° over-wrap angle . With the same operating conditions, 2 & 3 mixed nodes were obtained at 0° over-wrap angle. When the pressure was 7.15 inches of water and the web tension was 0.167 lb/in, the web was vibrating at 3 nodes at 4° of over-wrap angle. For the same operating conditions, buzzing and 2 nodes mixed flutter occurred at 0° over-wrap angle. The over-wrap angle was so sensitive that the test results were not repeatable unless the test conditions were exactly the same. A minor change in the operating conditions can cause a difference in the results.

Tension (lb/in)	Pressure (in. of water)	Over-Wrap angle (Degrees)	Mode
0.125	7.00	0.0	2 & 3 nodes mixed
0.125	7.00	2.0	3 nodes
0.125	6.85	6.0	Bumping
0.167	7.15	4.0	3 nodes
0.167	7.15	0.0	Buzzing & 2 nodes mixed
0.167	6.95	1.0	2 nodes
0.167	6.95	3.0	3 nodes
0.250	7.00	6.0	3 nodes

Table 3.1 Over-Wrap Angle with different Modes for 9.5" web span and 6" width, Chen (1996)

Effect of tension

It had been found that frequency increases with increase in web tension. This happens regardless of whether there is an air leakage or not. We can see this in figure 3.12. If the tension is 0.125 lb/in and the gap on both sides is 0.083% of the web width, the phenomenon is more complex: several modes appear simultaneously. By keeping one side gap fixed and increasing the other, the phenomenon is more stable until it becomes three modes. The closer the side plates are to the web edge the unstable is the flutter. Similar results were obtained with 0.25-lb/in. web tension

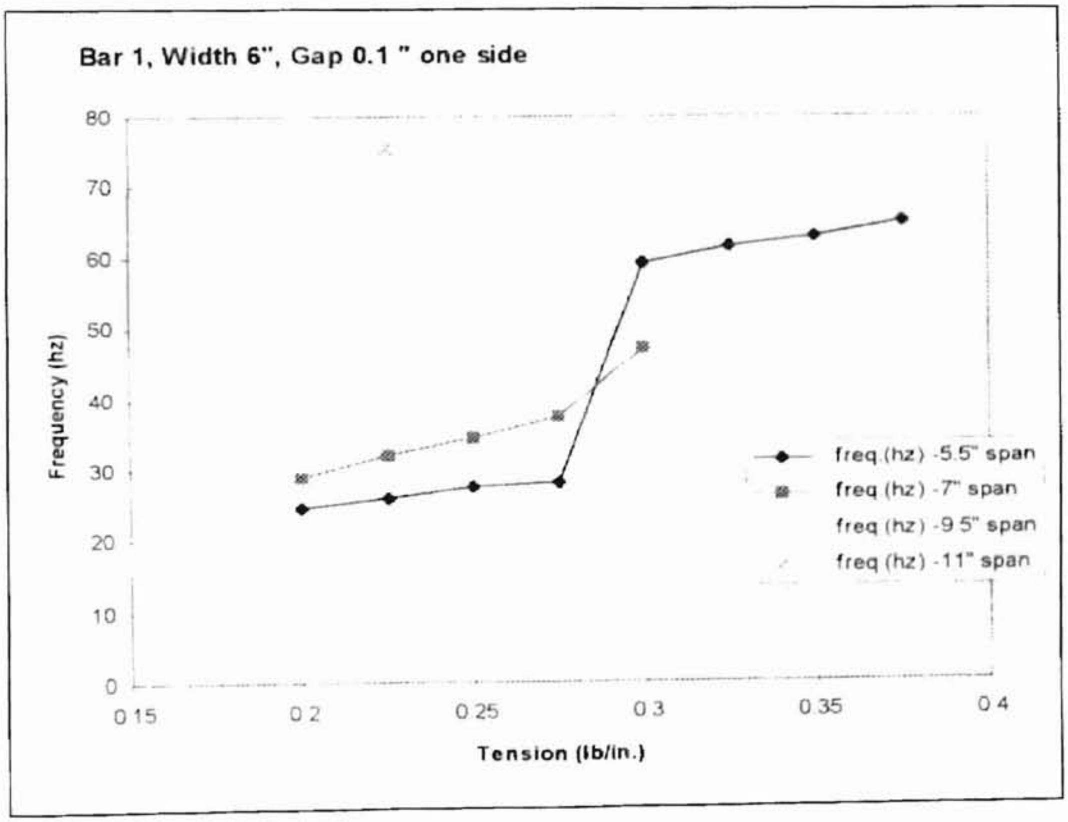


Figure 3.12 Effect of Tension on Flutter, Chen (1996)

Effect of Pressure

The effect of pressure was tested with a constant web tension of 0.2 lb/in and a web span of 9.5". We can see from the figure 3.13 that there is not much effect of pressure on frequency. With a pressure change from 0.16 to 0.24 inches of water there is very small frequency change of 1.5 Hz. Amplitude is affected by the pressure change: with the same pressure change there is an amplitude change of 3.6 mm/s, as shown in figure 3.14.

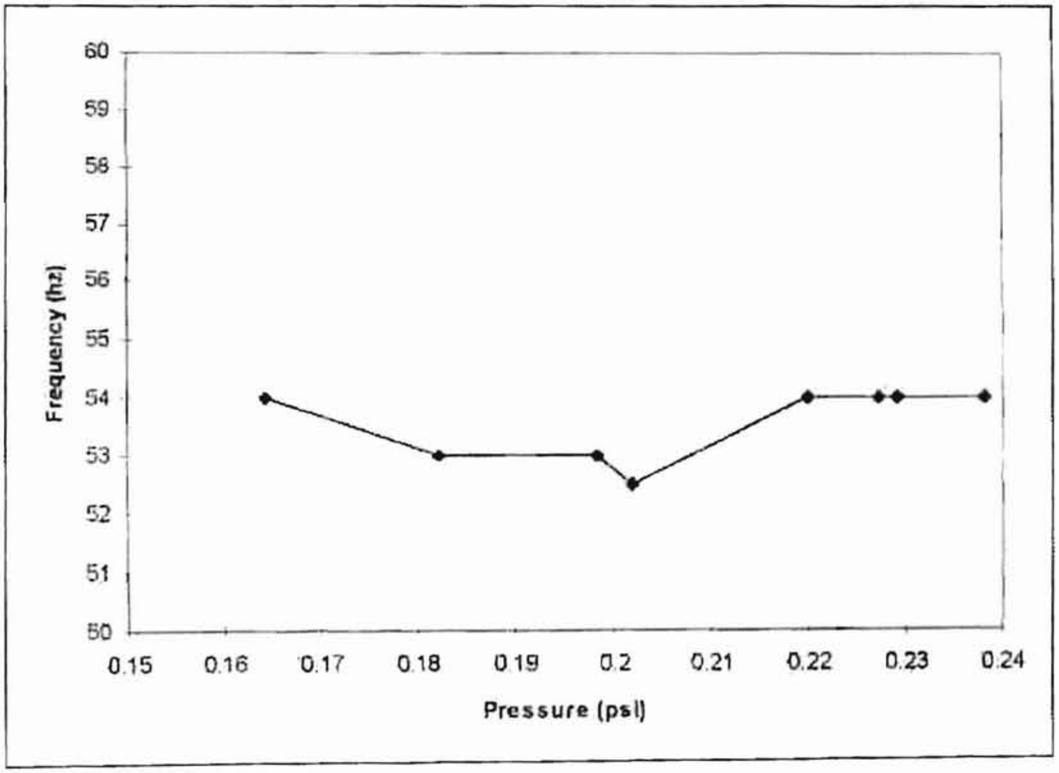


Figure 3.13 Effect of Pressure on Flutter, Chen (1996)

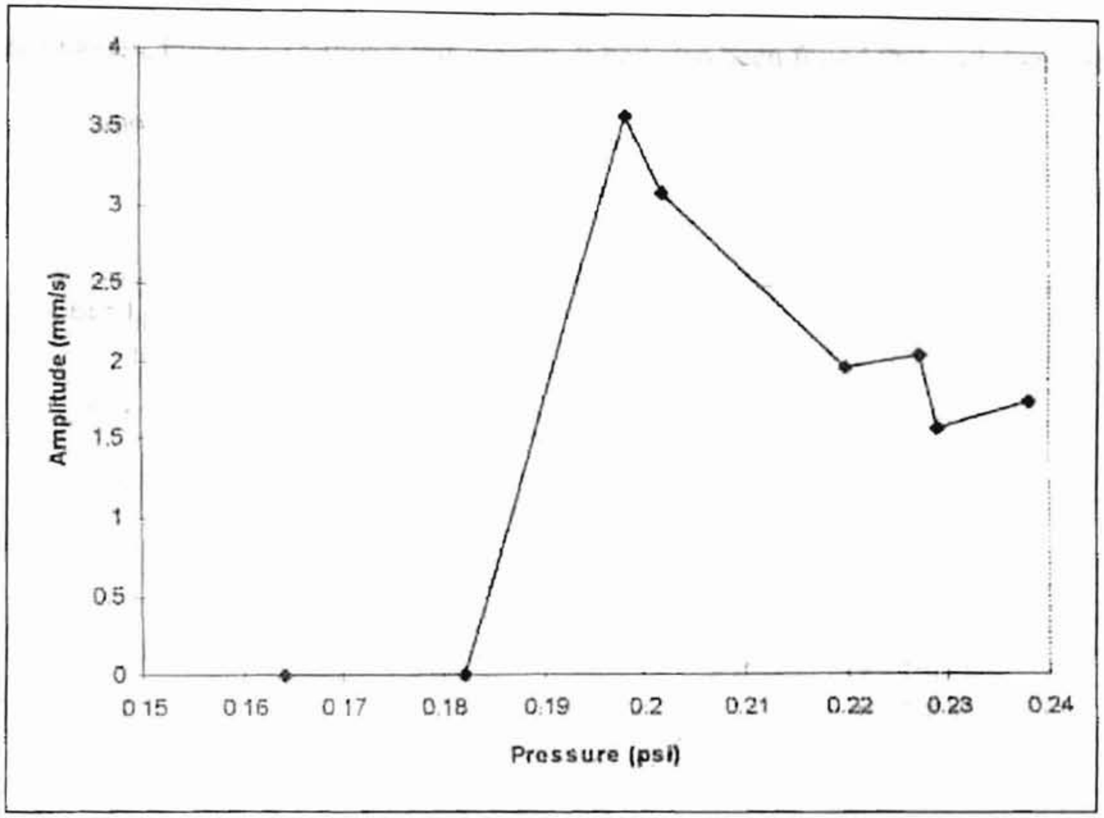


Figure 3.14. Effect of Pressure on Flutter, Chen (1996)

Effect of web length

According to Chen, there is an increase in frequency with increase in the web span. Unexpectedly, frequency increased with increase in the web span, jumping to higher modes. Figure 3.15 shows this clearly. It had also been found that with increase in web span, the number of nodes also increased.

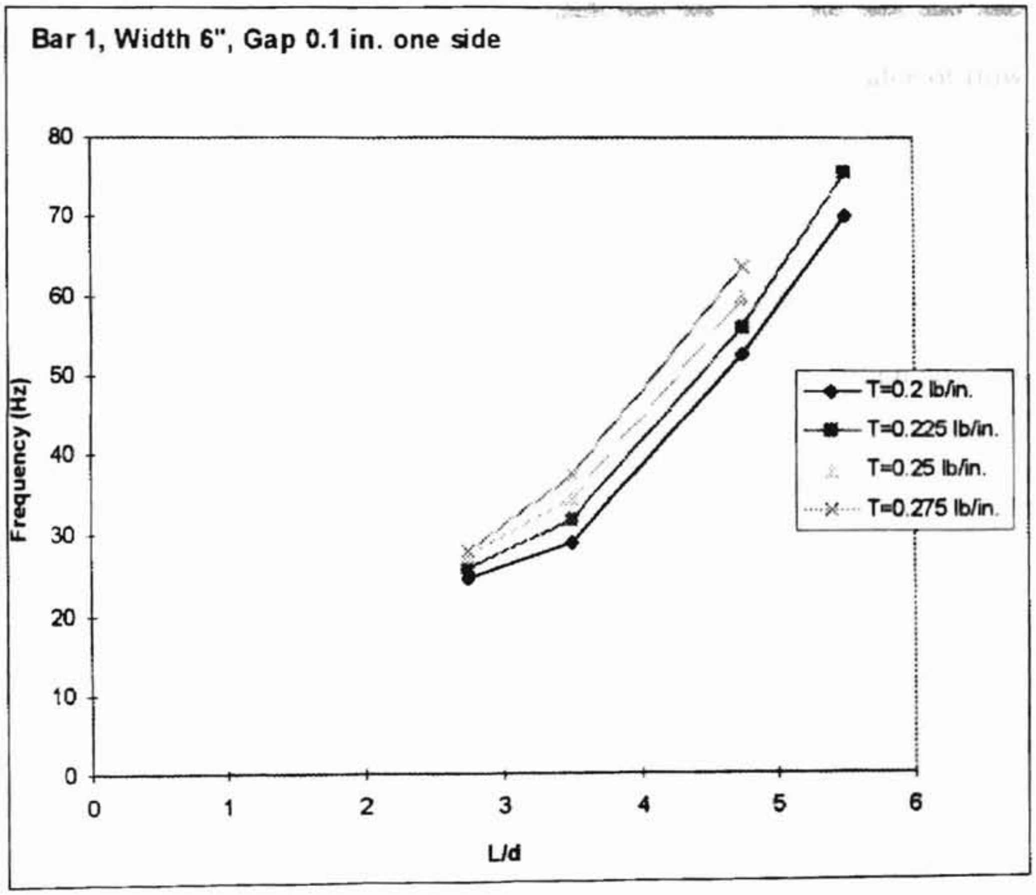


Figure 3.15 Effect of Web Span on Flutter, Chen (1996)

3.3 Edge Flutter

Cho (1999) conducted experiments using wind tunnel built around an infinite-loop web machine (shown in figure 3.16). Four rods were mounted on the outer surfaces of the wind tunnel walls, and the web was in contact with them during the experiments. Two laser-Doppler vibrometer were used for two-point non-contact measurement of the web flutter.

Following conclusions were obtained from the experiments:

- For any combination of operating conditions, there is a certain value of flow velocity above that a large amplitude edge flutter occurs.
- Web flutter can effectively be suppressed by increasing web tension.
- Flutter frequency, amplitude, and wave speed tend to increase with flow speed.
- Flutter frequency is strongly affected by altering the flow condition downstream of the web.

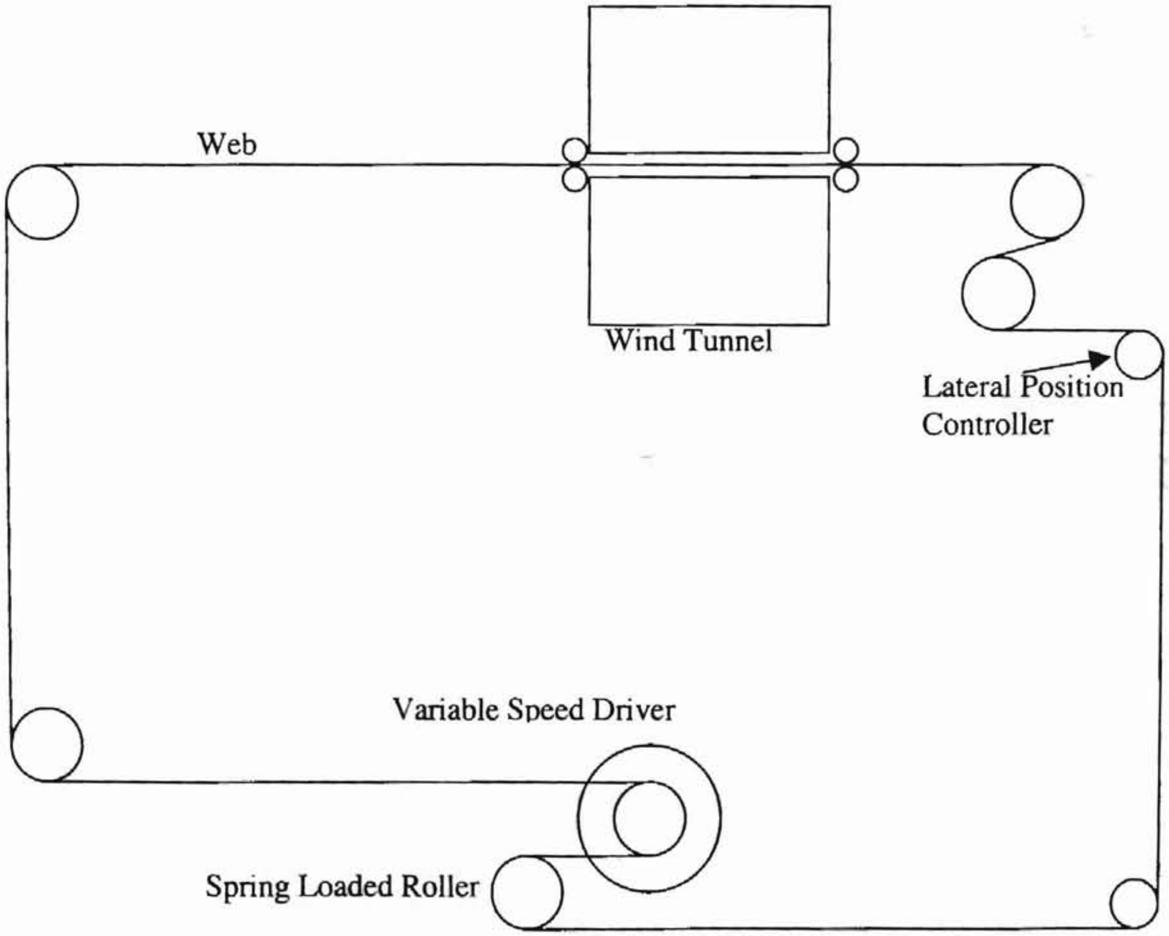


Figure 3.16 Schematic Diagram of Wind Tunnel

CHAPTER 4

"BUZZ"

4.1 Experimental Setup

The experimental setup for the air-reverser and the web is show in figure 4.1. In this test setup, both ends of the air-reverser are connected to an air supply through a pressure regulator and an air-filter, to vary pressure and flow of the air and to remove the moisture from the air supplied to the air-reverser, respectively. There were two dial pressure gauges and a manometer connected to the experimental setup. One of the dial pressure gauges was connected to the incoming air supply and the other dial pressure gauge was connected after the pressure regulator to measure pressure in atm and psi. Two pressure tabs taken out from the air-reverser were connected to the water manometer, measuring pressure in inches of water, by a three-way valve connecting only one pressure tab to the manometer at a time. Tests were conducted with a constant web length of 24" and web thickness of 0.01". 2" schedule 40 plastic pipe was used to make air-turn bar. Wrap-angle was changed by moving the roller supporting the web adjacent to the air-reverser as shown in figure 4.1. Wrap-angle reading in degrees was taken directly from the dial, mounted on the circumference of the air-reverser at the point where the web departs the air-reverser. An endless web was provided with three rollers and an air-reverser support for movement. This helps to see whether the web is touching or floating.

One laser-Doppler vibrometer was used to measure the "buzz" frequency along the flow direction. The laser-Doppler vibrometer consists of two components, a sensor head (Polytec OFV 350) and a vibrometer controller (Polytec OFV 2600). Signals were filtered from the vibrometer by a low pass filter (Active filter, Data Precision Model AF-120). A signal-analyzer was used to sample and analyze the signals from the low pass filter. A schematic diagram of the measuring equipments setup is shown in figure 4.2.

Every reading of the frequency documented was an average of 30 samples. Amplitude of the web vibration can be calculated by converting the voltage to velocity by using equation 4.1.

$$A = a * a / 125 \qquad 4.1$$

Where A is amplitude of the vibration (m/s), "a" is signal amplitude read from the signal analyzer, (Vrms ^ 2), and 125 is the proportionality constant for the laser- Doppler signal level which is from the relationship 1 volt = 1/125 m/s.

The vibrometer measurement location was at the center of the web span.

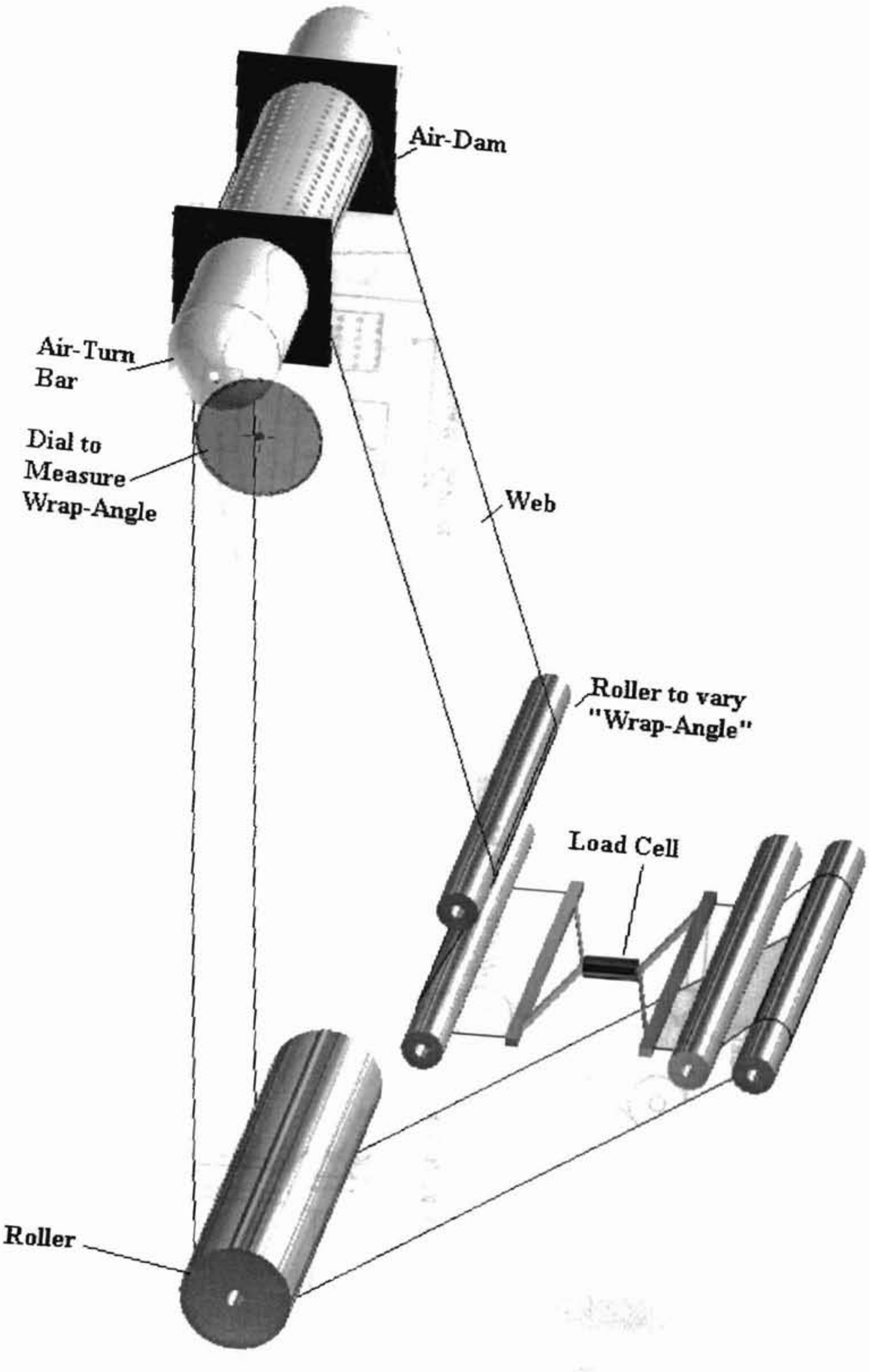


Figure 4.1 Schematic Diagram of Experimental Setup

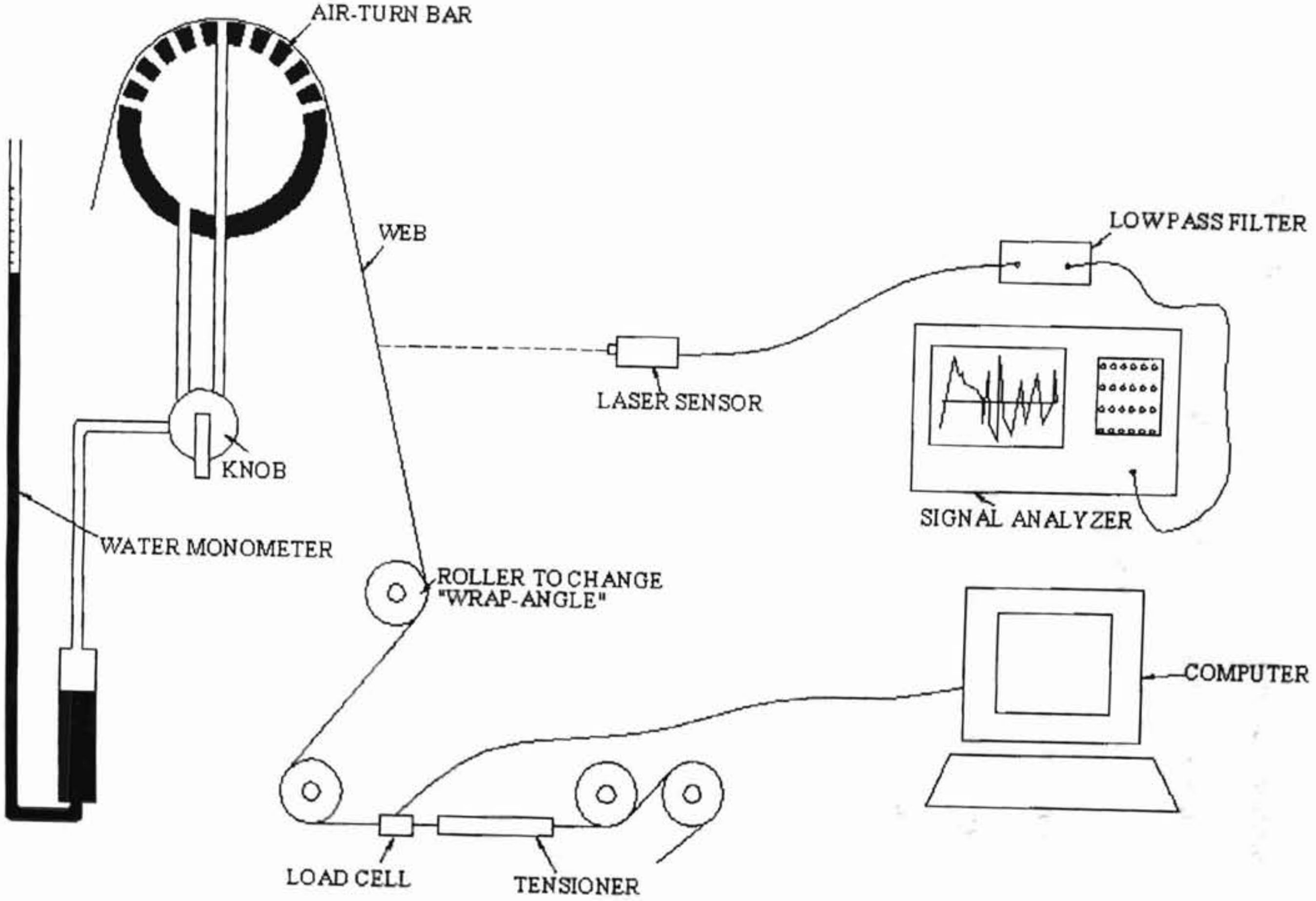
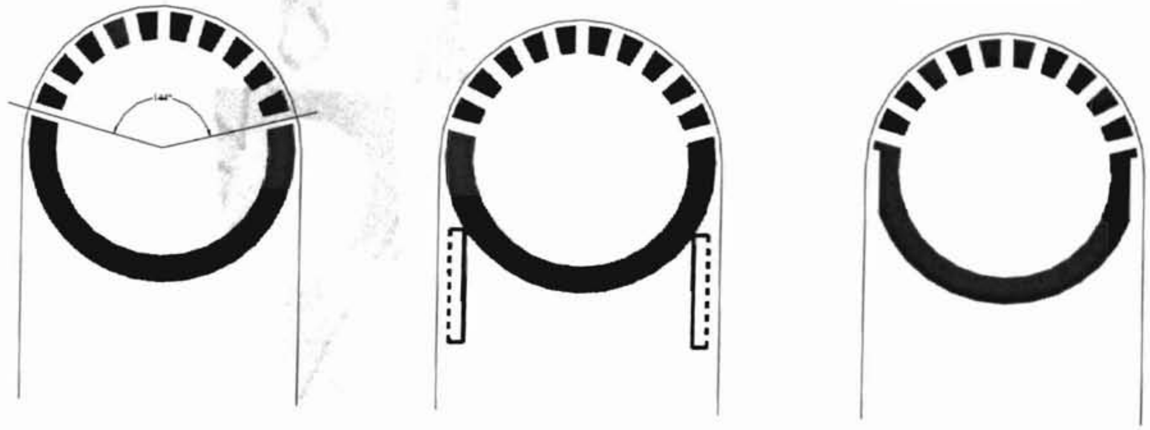


Figure 4.2 **Schematic Diagram of Measuring Equipments Setup**

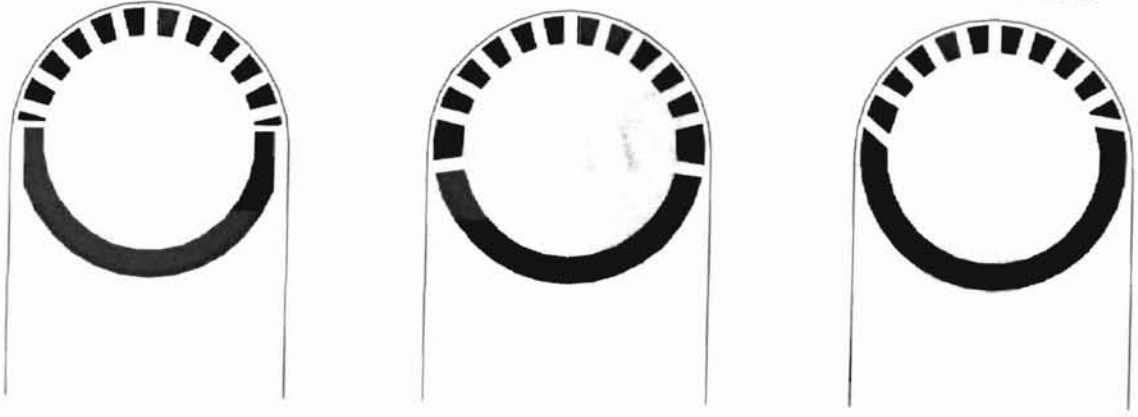
4.2 Experimental Plan

1. Set up a standard air-turn bar as a reference case (bar should be constructed form thick material in such a way that similar-but-modified bars can easily be constructed for later modified air-turn bar tests) to see the following:
    a. Can we replicate earlier experiments?
    b. Is the dependence on wrap angle, tension and pressure, etc, reproducible?
    c. Can we find reference set of conditions that always buzzes?
2. Construct and test, modified air-turn bars under comparable conditions as shown in figure 4.3:
    a. With a damping screen added.
    b. With a sharp separation notched edge into the bar.
    c. With a sharp separation notched edge and extra row of holes.
    d. With an extra row of holes.
    e. With an angled holes in end rows.
    f. With a damper plate at the roller (figure 4.4).


STANDARD
AIR-TURN BAR

AIR-TURN BAR
WITH DAMPER SCREEN

AIR-TURN BAR
SHARP NOTCH


AIR-TURN BAR
NOTCH AND AIR HOLES

AIR-TURN BAR
EXTRA ROWS OF HOLES

AIR-TURN BAR
ANGLED END ROW HOLES

Figure 4.3 Proposed Modified Air-Turn Bars

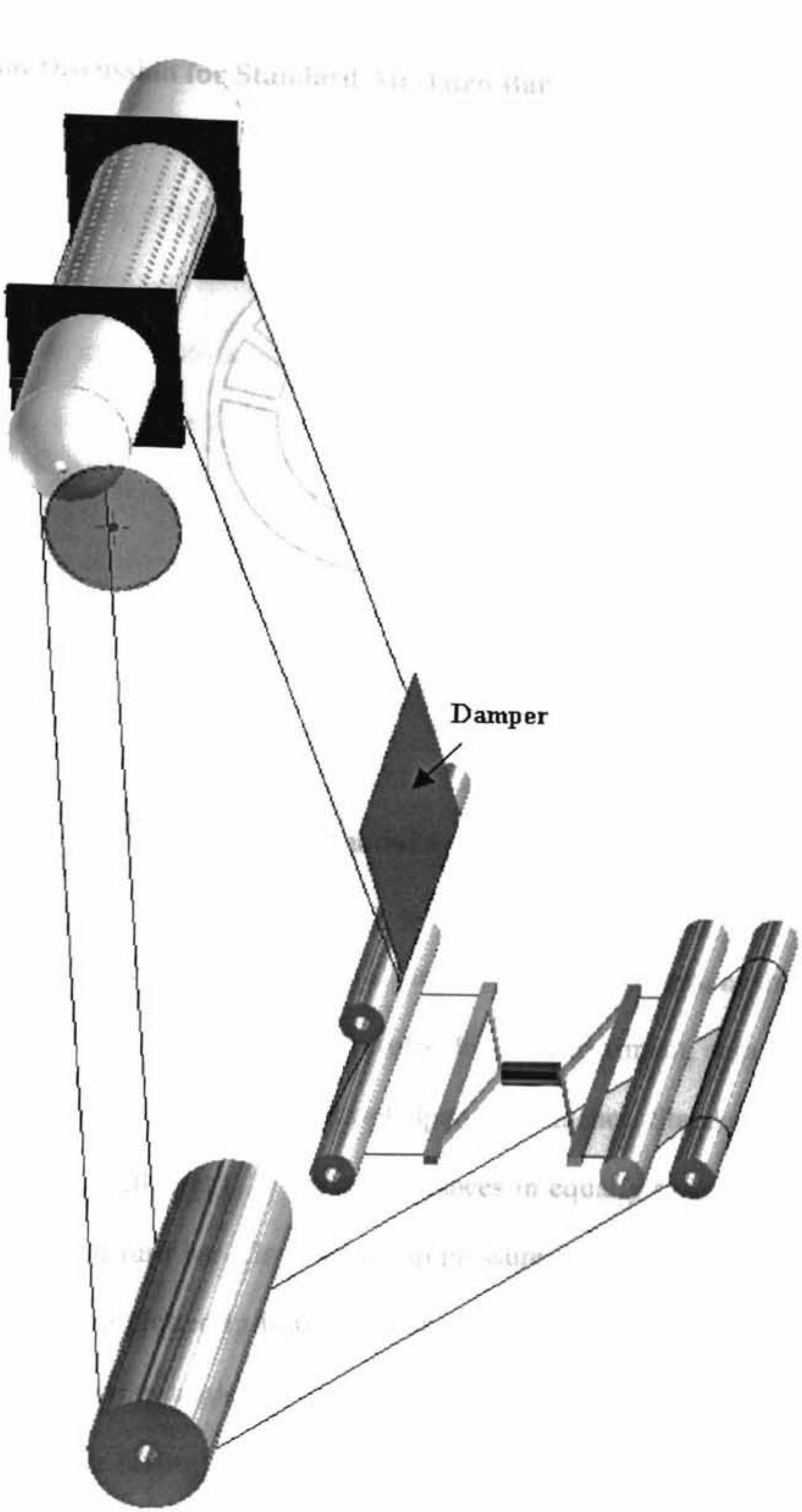


Figure 4.4 Air-Turn Bar with Damper at the Roller

4.3 Results and Discussion for Standard Air-Turn Bar

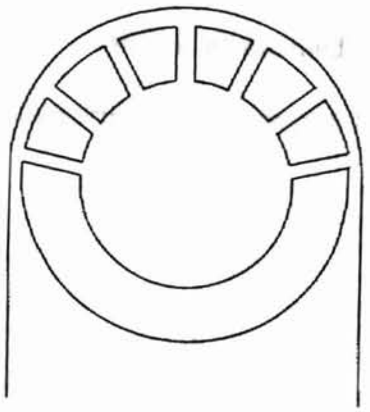


Figure 4.5 Standard Air-Turn Bar

It has been assumed that there is no air leakage from the edges, as the air leakage from the edges has little influence on the results. In this experiment, data was collected for air-turn bar with 0.125" hole rows and web span of 24 inches. Standard 6" web width was used. Holes were drilled at 0.25" center distances in equally spaced 9 rows in 144° circumference of the air-turn bar. Graphs for gap pressure (in. of water), tension (lbs/in.) and over-wrap angle are plotted in figures 4.6 and 4.7. Figure 4.6 shows graph between gap-pressure and over-wrap angle and figure 4.7 shows graph between web-tension and over-wrap angle. While taking these readings only the pressure was varied and not the tension, because increase in tension causes touching after reducing the gap between the web and the air-reverser. Condition of the web at air-turn bar has roughly been divided into four categories depending on the intensity of noise:

1. Web floating without any noise is considered "floating".
2. Web floating with slight humming noise considered "slight buzz".
3. Web floating with bearable noise is considered "mild buzz".
4. Web floating with unbearable noise is named as "heavy buzz".

If we see trend of graph 4.6 in vertical direction we find that, with increase in gap-pressure there is an increase in the "buzz" as already found in the research of Chen (1996). At all over-wrap angles, increase in pressure has increased "buzz" intensity. We found similar effect of the web-tension on the "buzz" as shown in figure 4.7. The most prominent factor for the web to buzz is found to be over-wrap angle. Figures 4.6 and 4.7 show that at higher over-wrap angle there is less buzz but with decrease in over-wrap angle there is an increase in buzz. In the range of 15° to 18° of over-wrap angle, only floating and "slight buzz" is found. Between 9° and 15° of over-wrap angle, "mild buzz" has also started showing up along with "slight buzz" and floating. Below 9° of over-wrap angle, "heavy buzz" is dominating until web started touching at 0° of over-wrap angle. At negative over-wrap angle there is more airflow because of excessive loss of air through the uncovered row of holes. Gap between the web and the air-turn bar doesn't have significant effect on "buzz", except to increase air loss. The pressure in the gap between the air-turning bar and the web is found to be continuously fluctuating because of the "buzz". The pressure fluctuation in the gap increases with an increase in pressure or web-tension at all over-wrap angles.

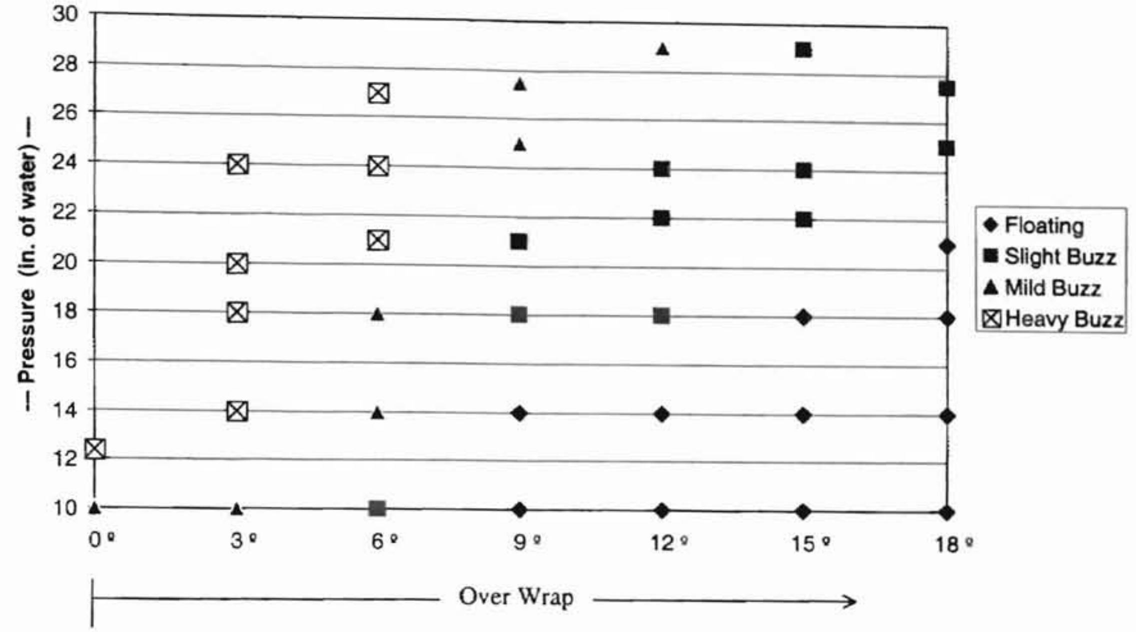


Figure 4.6 Effect of Gap-Pressure and Over-Wrap Angle on Buzz for Standard Air-Turn Bar

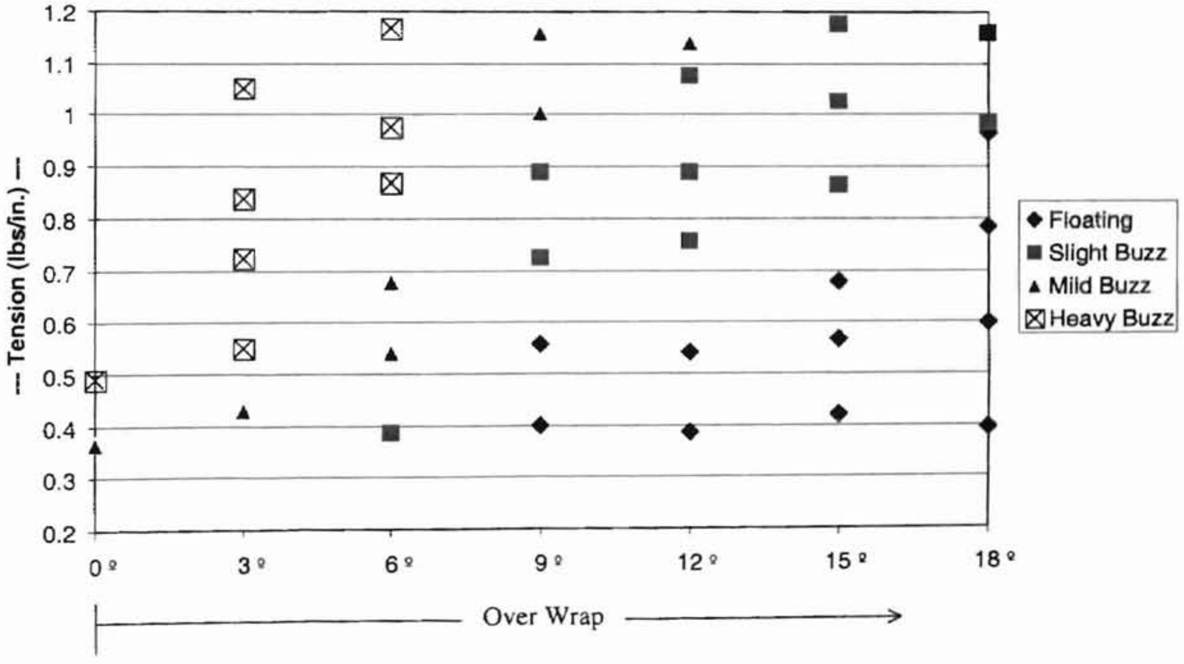


Figure 4.7 Effect of Tension and Over-Wrap Angle on Buzz for Standard Air-Turn Bar

4.4 Air-Turn Bar with Damping Screen

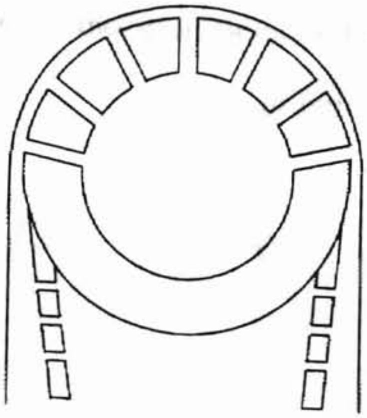


Figure 4.8 Air-Turn Bar with Damping Screen

In this test setup one damping screen was mounted at the point of departure of the web from the air-turn bar. The damping screen was made with a 6" ×3.5" steel plate and has .125" diameter holes drilled in it, in the same order as on the air-turn bar. There was also a provision for blowing air through these holes. An air tab was taken out to check the pressure of the air blown through these holes. Rest of the test setup was same as standard test setup. There was also a provision to vary the gap between the web and the damping screen.

Web pressure and tension have the same effect on the "buzz" at all over-wrap angles as seen in the previous experiment. Figure 4.9 and 4.10 show that the "buzz" increases with increase in the web tension and gap-pressure. From figure 4.9 and 4.10, it is clear that introduction of the damping screen has reduced the "buzz" significantly at all over-wrap angles. Damping screen has outstanding effect at higher over-wrap angles. There is slight or no "buzz" above 9° of over-wrap angles. From 3° to 6° of over-wrap angle we find that "mild buzz" comes into picture. At 0° of over-wrap angle, web starts buzzing with "heavy buzz". Any further decrease in over-wrap angle caused touching of the web with the air-turn bar as seen in standard air turn bar test. Here the gap between the web and the damping screen bar has great influence in reducing the "buzz". With a minimum parallel gap of 2mm between web and the damper screen we got the best results. Damping screen was also tested for angled gap but no significant results obtained at any over-wrap angle. Blowing air through the holes of the damping screen caused touching at all over-wrap angles web. There was little drop in pressure by using damping screen, and the web was found to be more stable at all over-wrap angles as compared to the standard test. Web stability might be a reason for the pressure drop.

[illegible] Turn Bar with Extra Row of Holes:

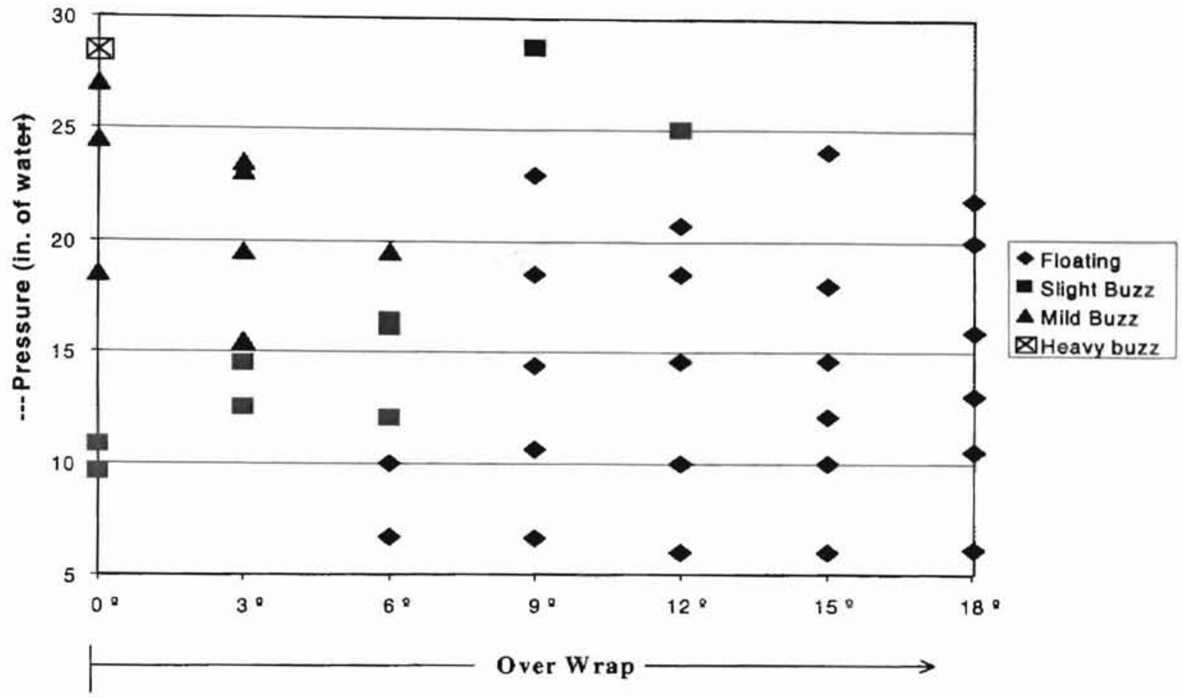


Figure 4.9 Effect of Gap-Pressure and Over-Wrap Angle on Buzz for Standard Air-Turn Bar with Damping Screen

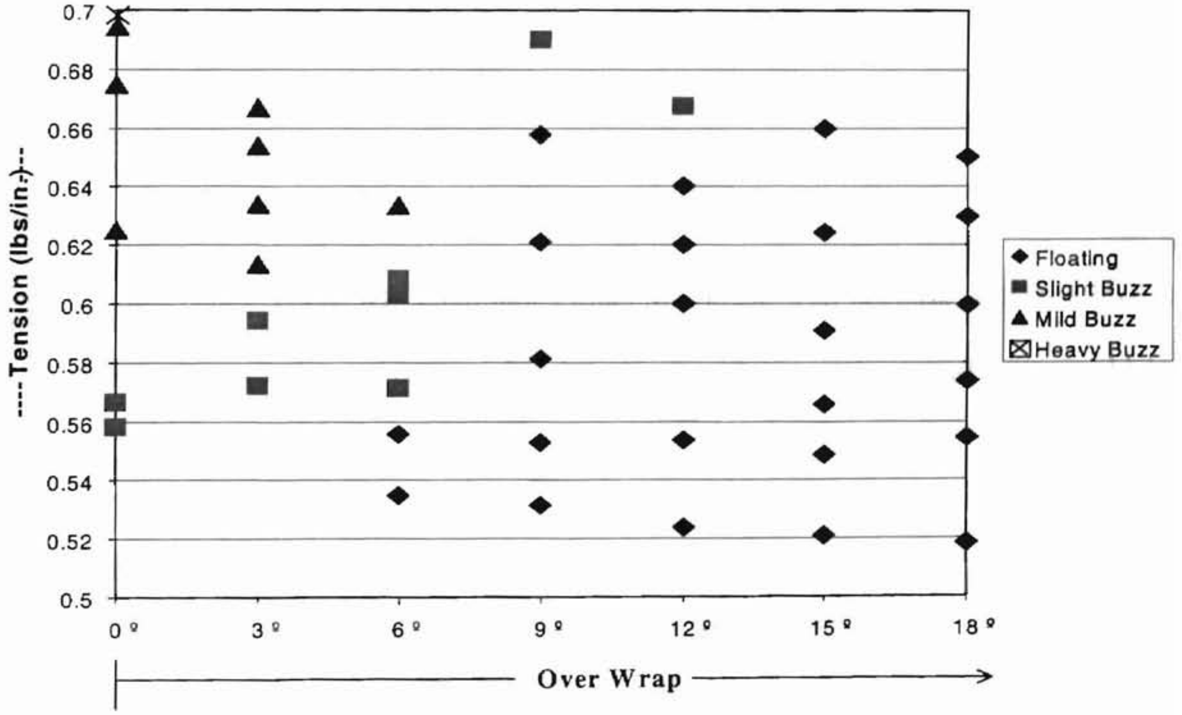


Figure 4.10 Effect of Tension and Over-Wrap Angle on Buzz for Standard Air-Turn Bar with Damping Screen

4.5 Air-Turn Bar with Extra Row of Holes:

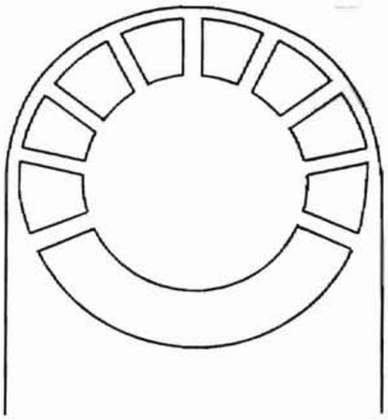


Figure 4.11 Air-Turn Bar with Extra Row of Holes

In this test setup an extra row of holes has been drilled on both sides of the air-turn bar at ½ inch away from the last row of holes rest of the test setup was same as standard test setup. There was continuous touching of the web because of heavy loss of air-pressure through the extra row of holes. No usable operating conditions could be obtained.

4.6 Air-Turn Bar with Sharp Notch, and Optional Row of Holes

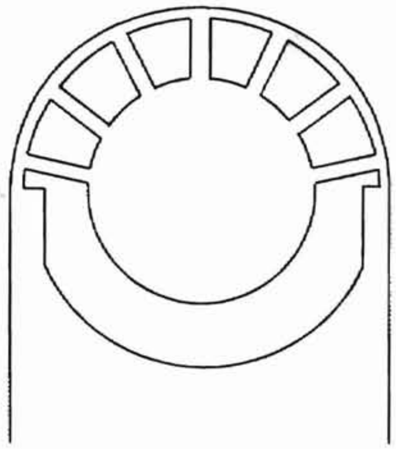


Figure 4.12 Air-Turn Bar with Sharp Notch

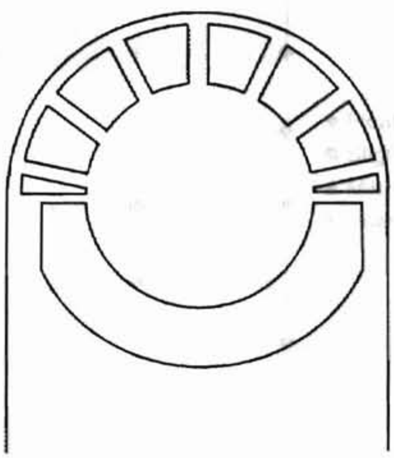


Figure 4.13 Air-Turn Bar with Optional Row of Holes

In this test setup, as shown in figure 4.12, air-turn bar with a sharp edge of 2mm depth and 1mm away from the last row has been machined. Rest of the test setup was same as standard test setup. The pressure and the web-tension have same effect on the "buzz" as found in the standard air-turn bar. If we compare graphs of figure 4.14 and 4.15 of this test with figure 4.6 and 4.7 of the standard test we find that the results are more or less same as standard test. There is no "buzz" found above 12° of over-wrap angle. Between 0° and 12° of over-wrap angle, web is vibrating with slight to heavy buzz depending on pressure and web-tension. Any further unwrapping of the web had caused heavy pressure loss through the uncovered rows of holes.

In the same test setup with optional row of holes in the notch as shown in the figure 4.13, there was a heavy loss of air-pressure through the extra row of holes in the notch, causing web touching. So no useful data was obtained.

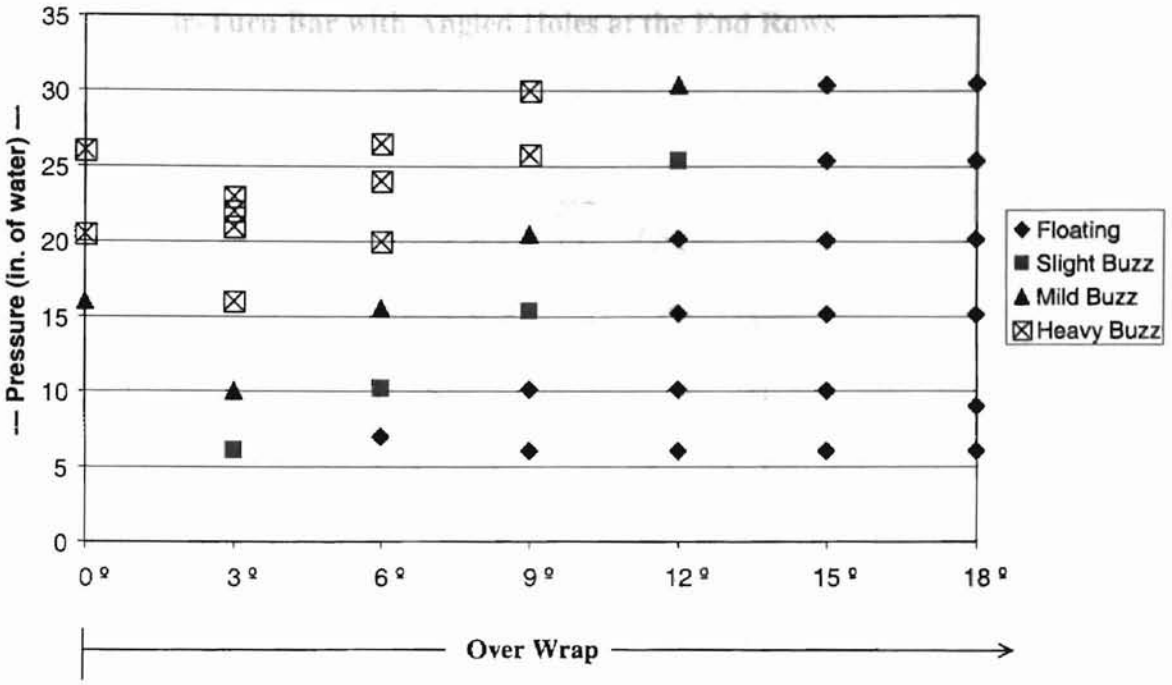


Figure 4.14 Effect of Gap-Pressure and Over-Wrap-Angle on Buzz for Standard Air-Turn Bar with Sharp Notch at end Rows

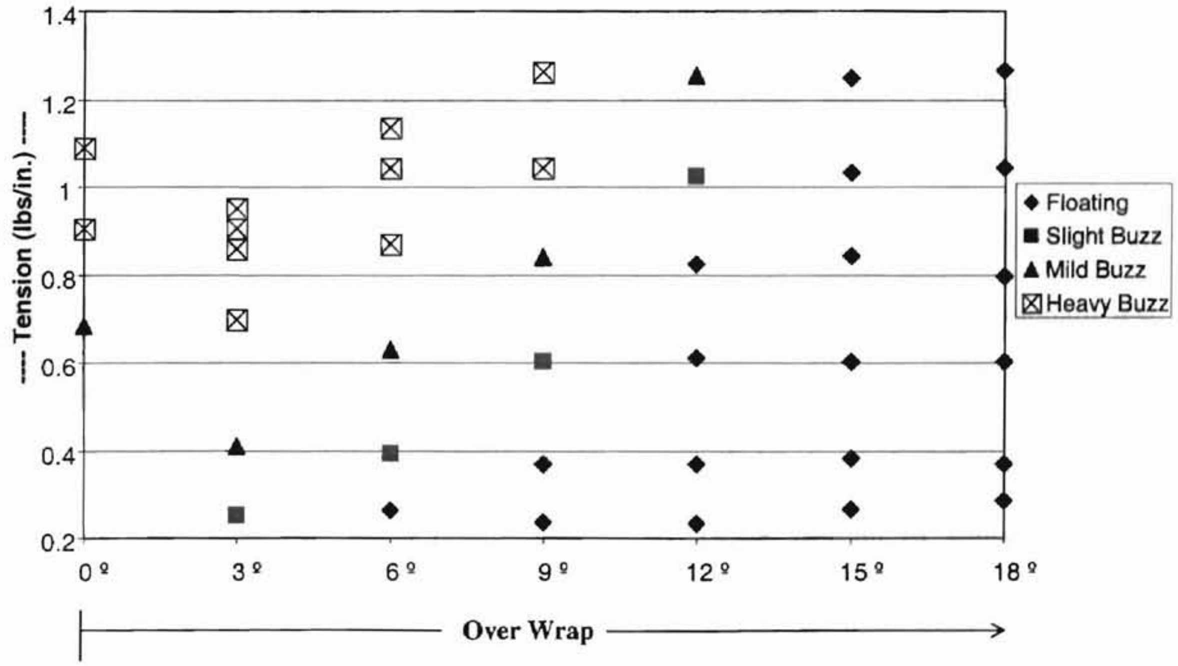


Figure 4.15 Effect of Tension and Over-Wrap-Angle on Buzz for Standard Air-Turn Bar with Sharp Notch at end Rows

4.7 Air-Turn Bar with Angled Holes at the End Rows

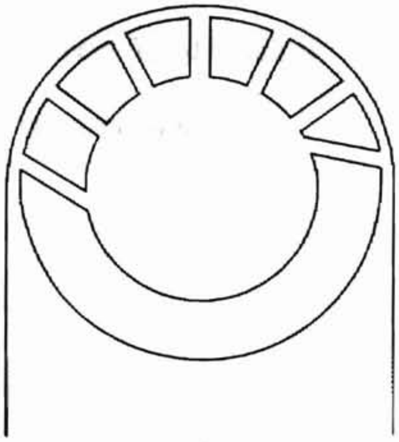


Figure 4.16 Air-Turn Bar with Angled Holes at the End Rows

This experiment had been done in two parts. In first part the air-turn bar with angled holes in upward direction at 30° to the normal had been tested. In second part, the holes direction had been set downward at 30° to the normal. Rest of the test setup was same as the standard test setup.

Comparing the figures 4.17 and 4.18 of the first part of this test and figures 4.6 and 4.7 of the standard test, we find that the results are worse than the standard test. Pressure and web-tension have the same effect on the "buzz" at all over-wrap angles as in the standard test. It seems that web is vibrating with all kinds of "buzz" except "heavy buzz" between 12° and 18° of over-wrap, depending on amount of web-tension and pressure. From –3° to 9° of over-wrap, web started vibrating with heavy buzz at high web-tension and pressure. Only improvement found in this test as compared to standard test is the floating of the web at –3° of over-wrap. Rest of the results are similar to the standard test.

By comparing figures 4.19 and 4.20 of the second part of this test with figures 4.6 and 4.7 of the standard test we find that results are more or less same as that of the standard test. Here we found the same effect of pressure and web tension on "buzz" at all over-wrap angles. Only improvement found in this test as compared to standard test is the floating of the web at –3° of over-over wrap.

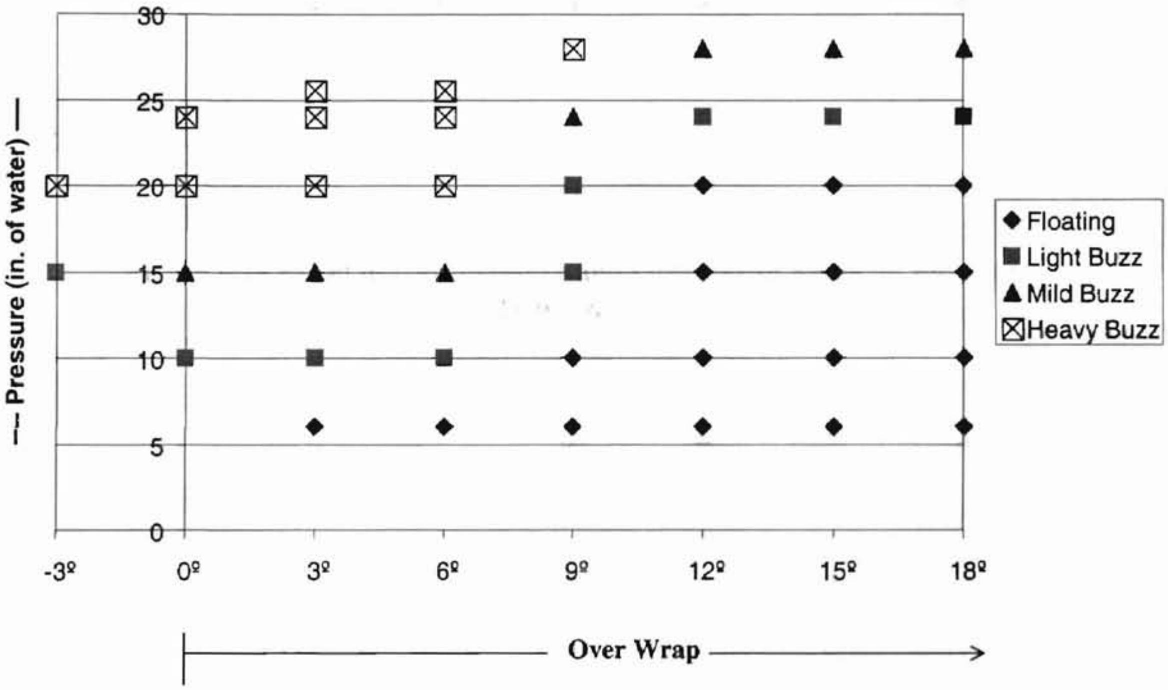


Figure 4.17 Effect of Gap-Pressure and Over-Wrap-Angle on Buzz for Air-Turn Bar with Upward Directed End-Holes

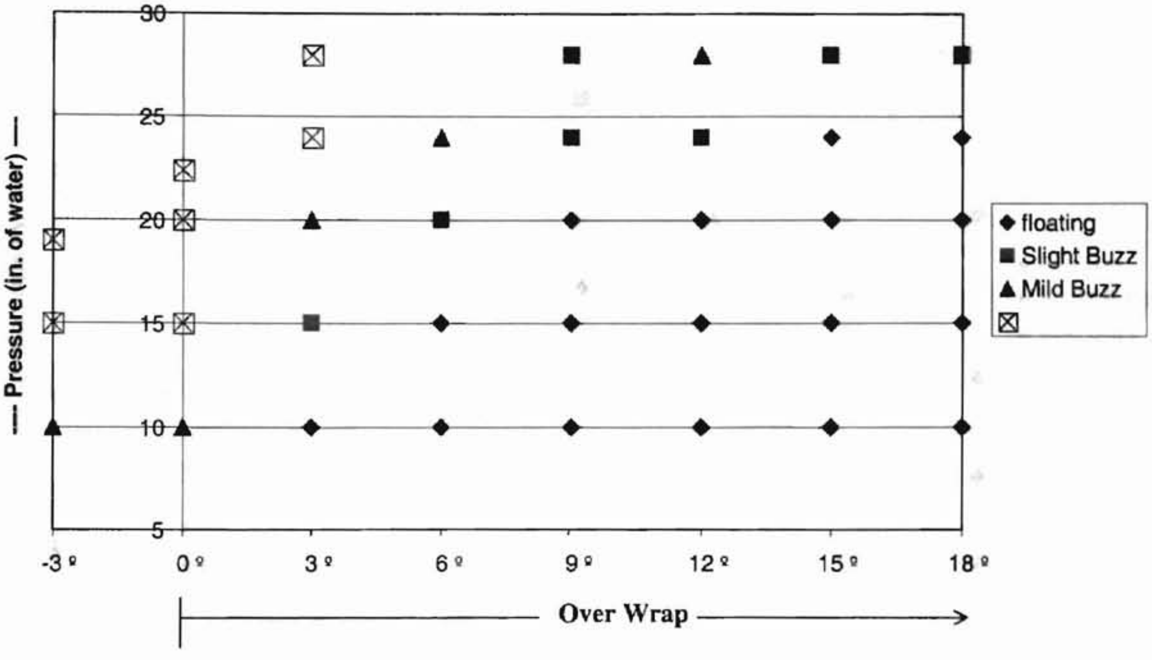


Figure 4.19 Effect of Gap-Pressure and Over-Wrap Angle on Buzz for Air-Turn Bar with Downward Directed End-Holes

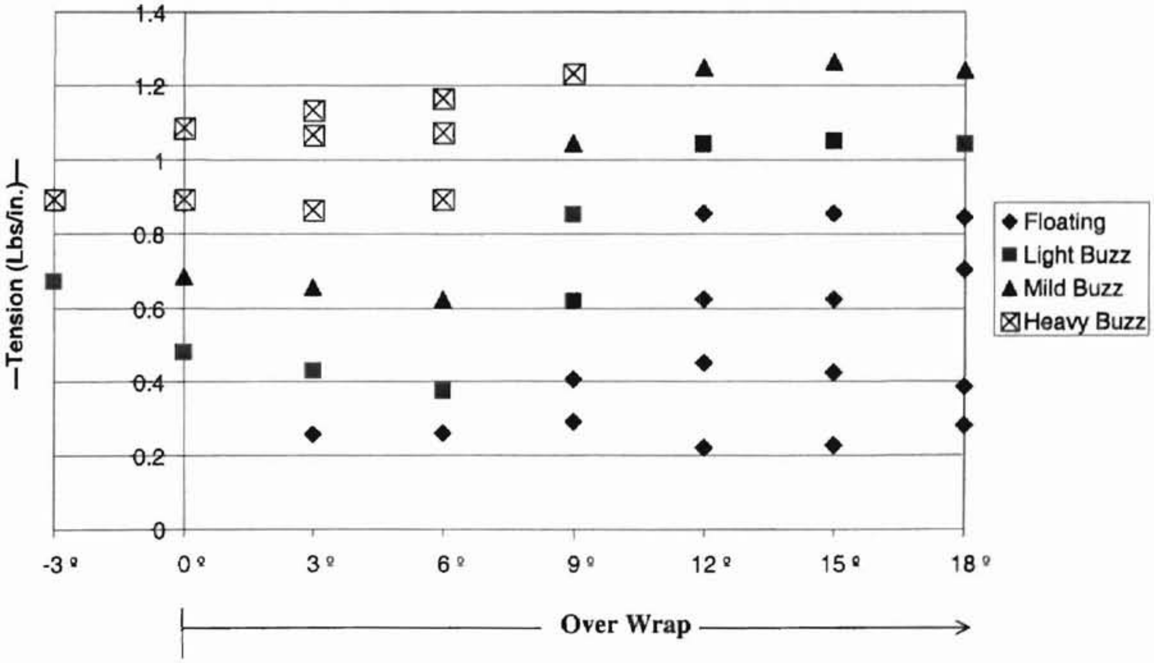


Figure 4.18 Effect of Tension and Over-Wrap Angle on Buzz for Air-Turn Bar with Upward Directed End-Holes

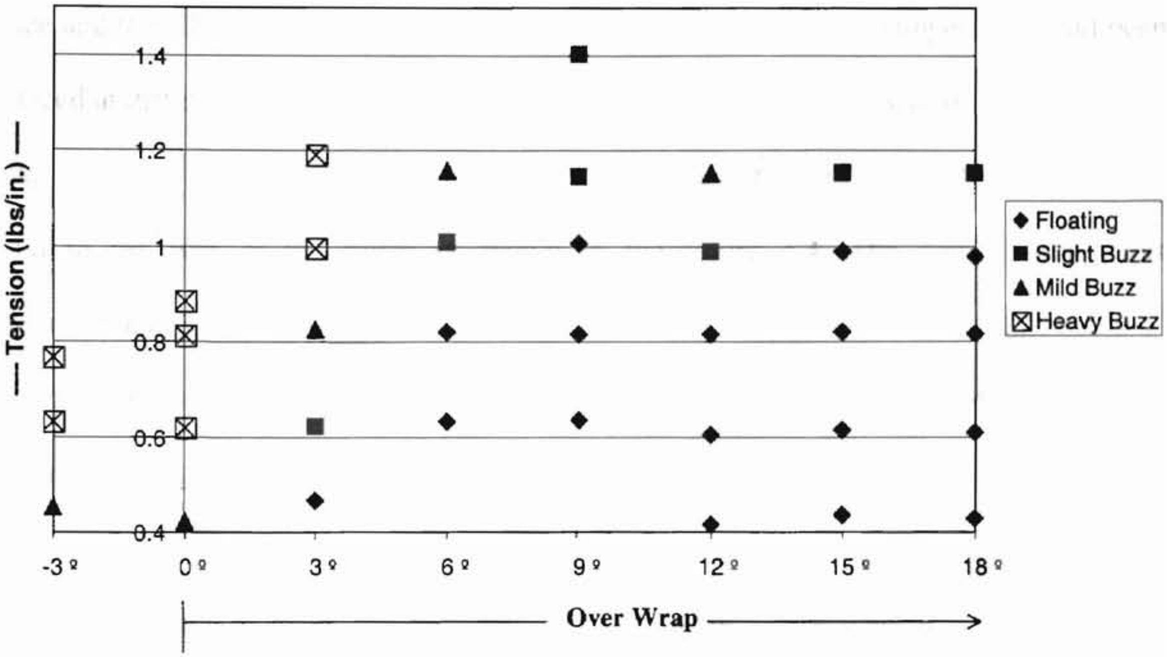


Figure 4.20 Effect of Tension and Over-Wrap Angle on Buzz for Air-Turn Bar with Downward Directed End-Holes

4.8 Damper plate at the Roller

In this test, setup was same as that of standard test setup except for a damper plate, 6"x6" size and 0.5" thick, was placed at the wrap-angle changing roller. Damper plate had been placed at different locations before getting this optimum position where minimum "buzz" was obtained. The damper plate was placed at an angle to the web almost touching its one end to the web at the roller as shown in the figure 4.4. The damper plate was approximately forming 2° angle with the web.

This test setup had given best results and buzz was eliminated completely at all over-wrap angles as it is obvious from figures 4.21 and 4.22. There is an increase in frequency with an increase in pressure or web-tension. With increase in pressure we found that there is an increase in hissing sound of air rather than increase in "buzz". There is no increase in the "buzz" at any variation in pressure at any over-wrap angle except at 3° of over-wrap, where we found "slight buzz" at 25 inches of water. There was almost no "buzz" at all over-wrap angles. It is obvious from the graphs 4.23 and 4.24, obtained from vibrometer, that the amplitude of the frequency has been reduced drastically by the use of damper plate at this position. There is slight lowering in air-pressure with the use of damper. The possible reason for the lowering in air pressure can be web stability.

Different damping materials had been tested at 28 inches of water and 3° of over-wrap. Plywood had given best results as compared to plastic, rubber or metal plate. Frequency graph for various damper materials has shown in figures 4.25 to 4.28. Variation in damper length had no significant effect on the "buzz". For this particular case 6" was minimum length of the damper-plate to obtain best results.

Air-turn bar with 0.1" and 0.75" holes had also been tested with and without damper. It is clear from figures 4.29, 4.30, 4.33 and 4.34 that even slight buzz, found in the previously tested air-turn bar with 0.125" holes with damper, has been disappeared. Web was even found floating at -3° of over-wrap as compared to standard air-turn bar. Experiments have also been done to find the effect of holes distribution on the "buzz". Figures 4.31, 4.32, 4.33, 4.34, 4.35, and 4.36 show that the "buzz" is not much effected by holes distribution.

Figure 3.37, shows the effect of web-span on the "buzz" for air-turn bar with 0.1" holes, at 10° of over-wrap and 30 (inches of water) pressure. This graph shows that there is an increase in frequency with decrease in web length.

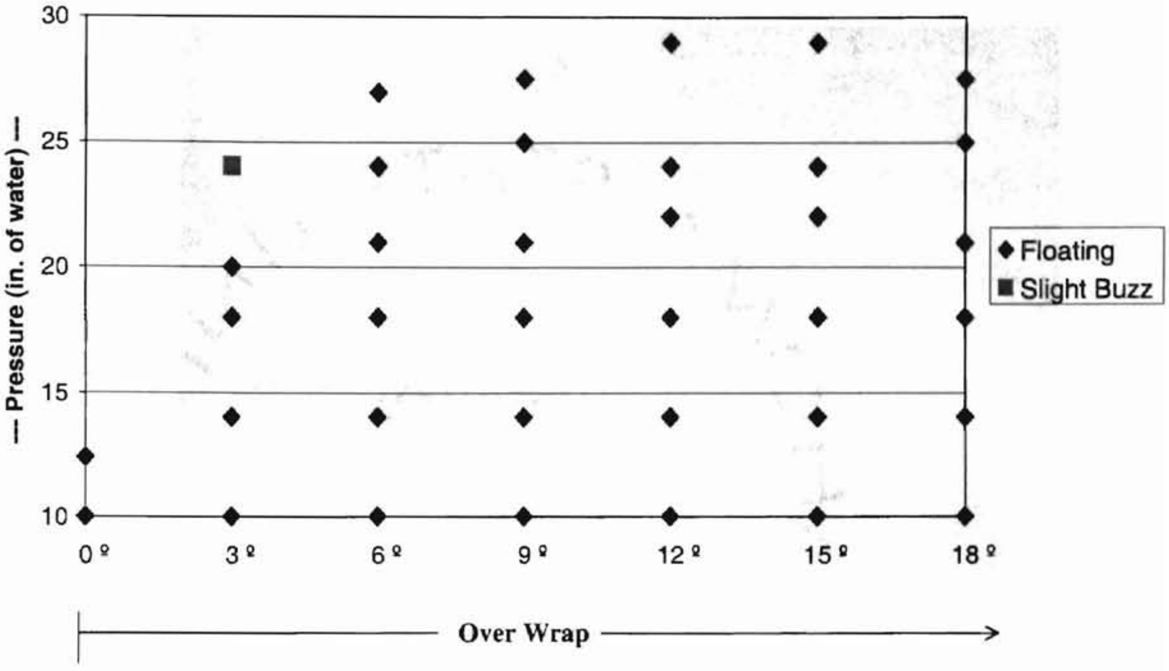


Figure 4.21 Effect of Gap-Pressure and Over-Wrap Angle on Buzz for Standard Air-Turn Bar with Damper at Roller

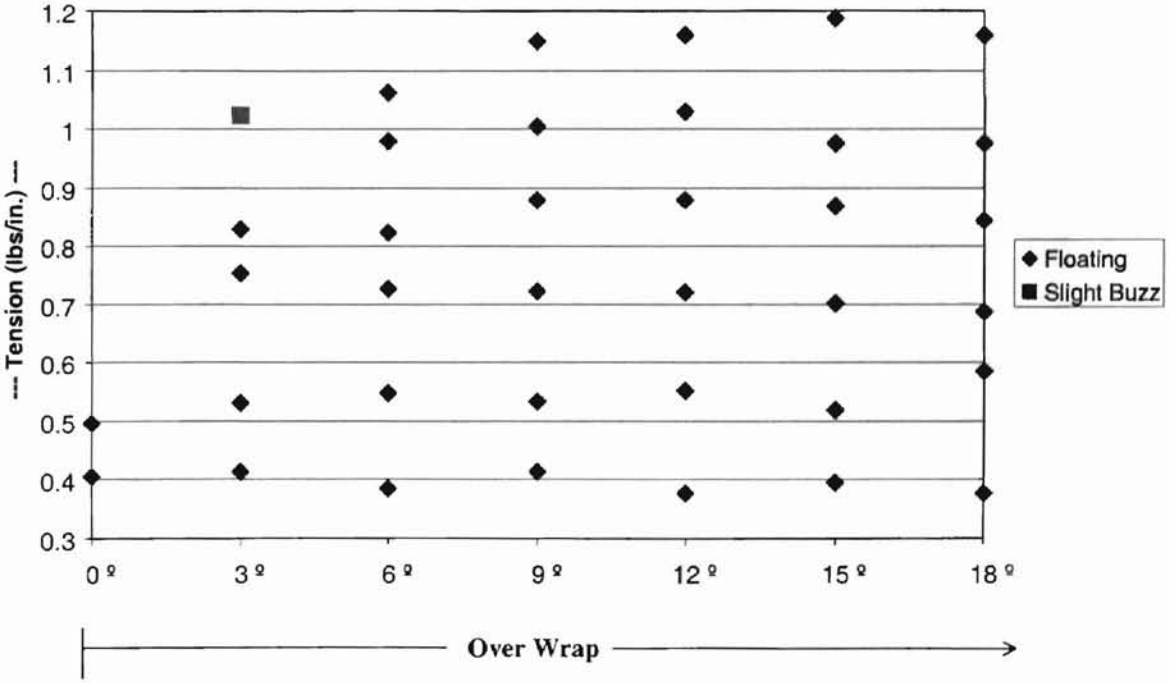


Figure 4.22 Effect of Tension and Over-Wrap Angle on Buzz for Standard Air-Turn Bar with Damper at Roller

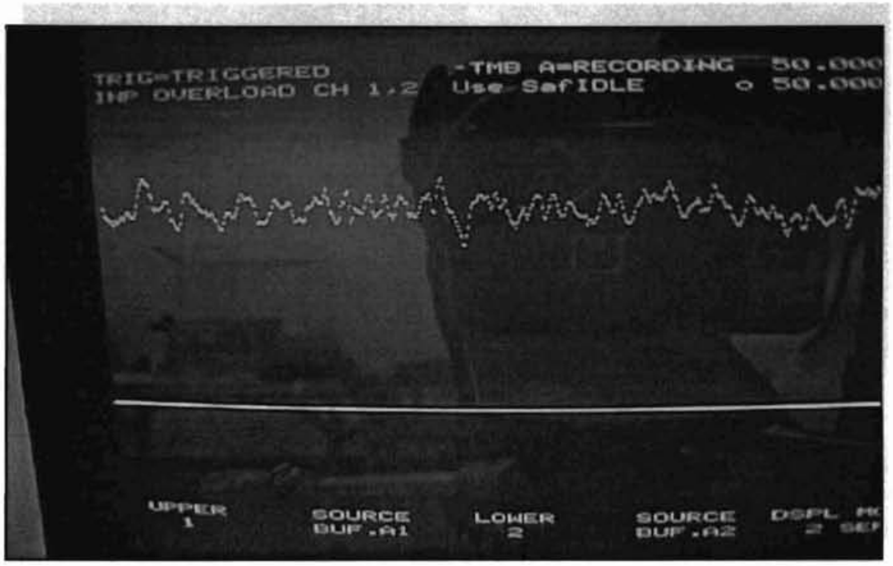


Figure 4.23 Frequency Graph for Plywood

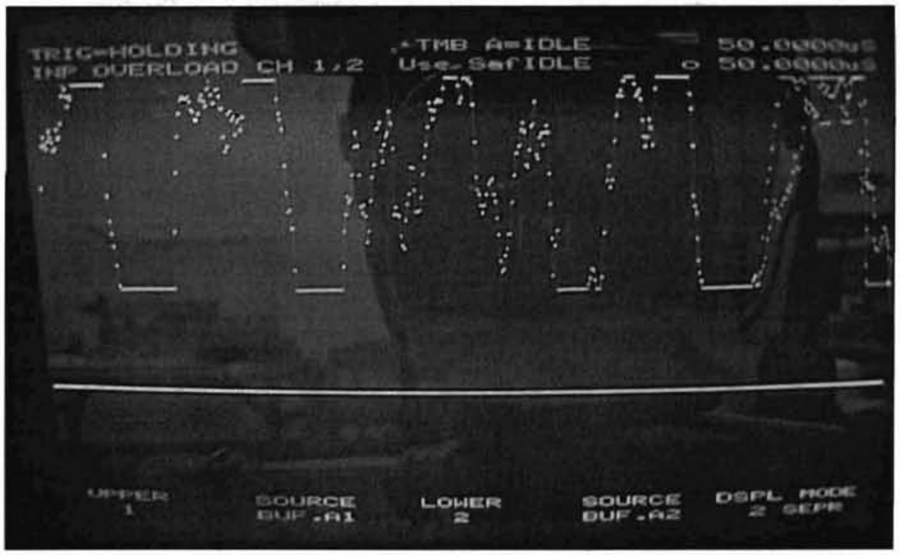


Figure 4.24 Frequency Graph without Damper

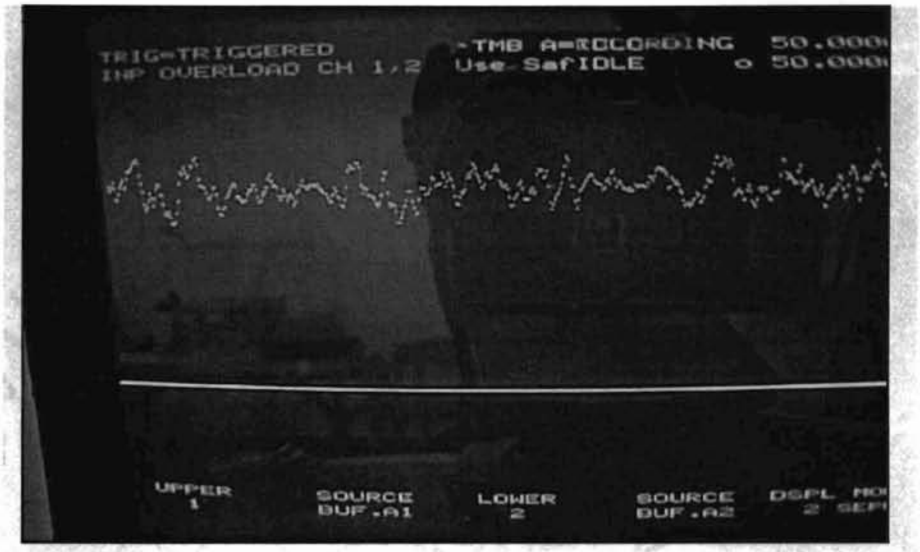


Figure 4.25 Frequency Graph for Hard Cardboard

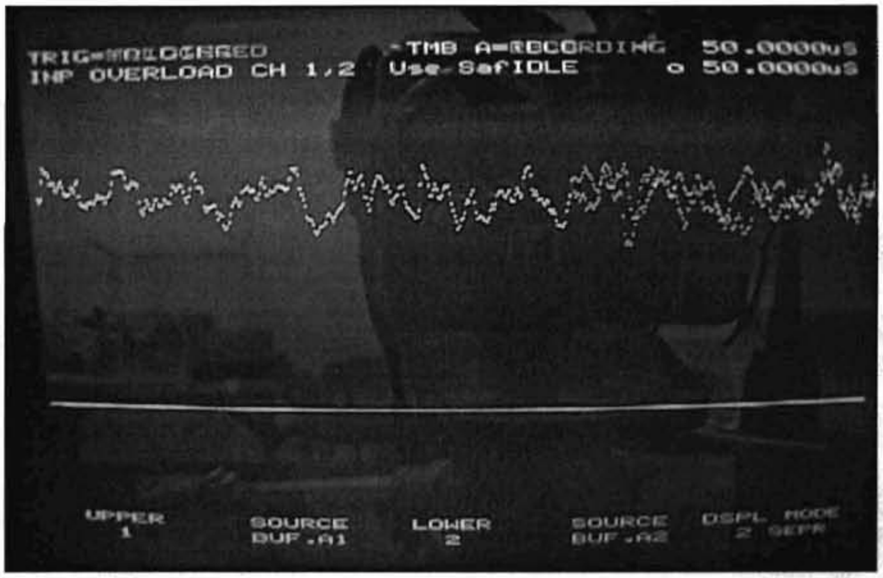


Figure 4.26 Frequency Graph for Metal Plate

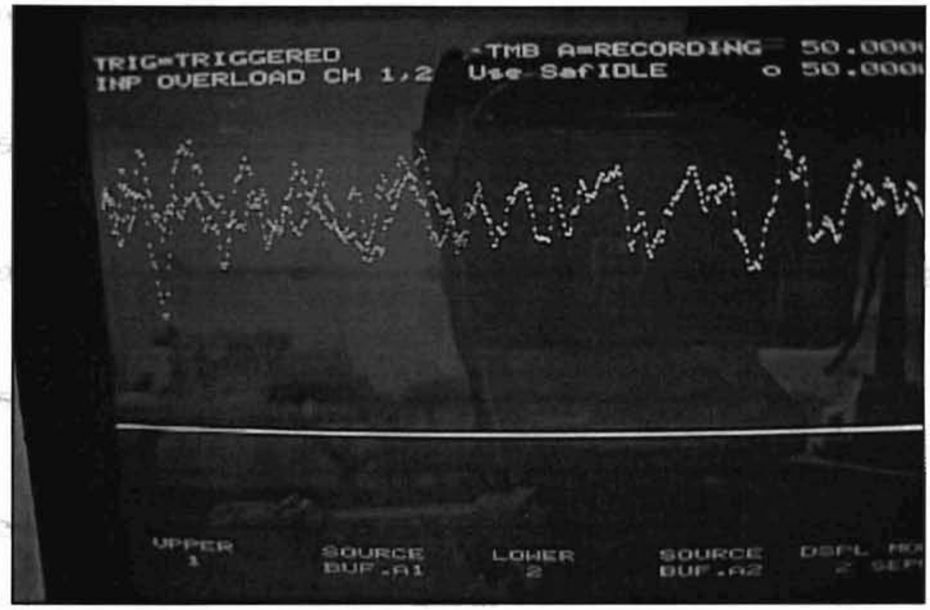


Figure 4.27 Frequency Graph for Thick Plastic Board

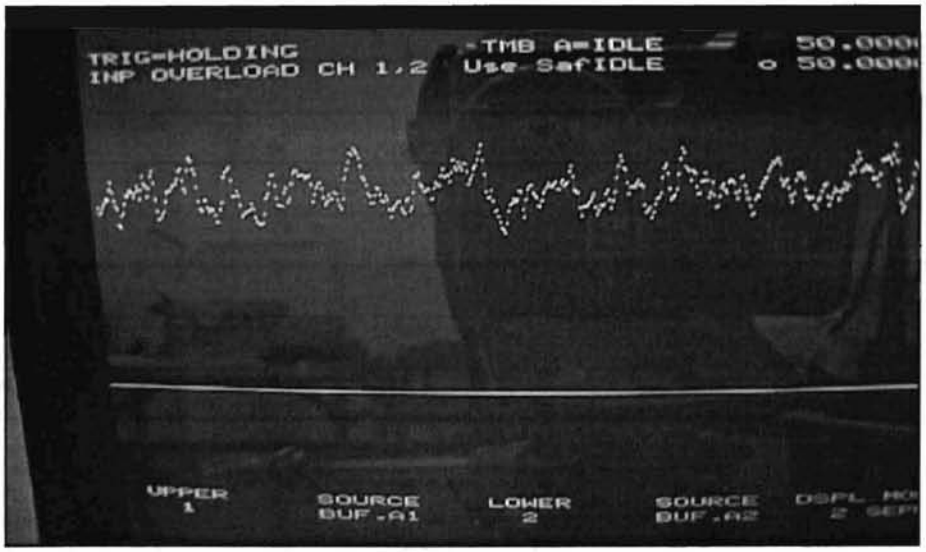


Figure 4.28 Frequency Graph for Thick Thermo Cole Board

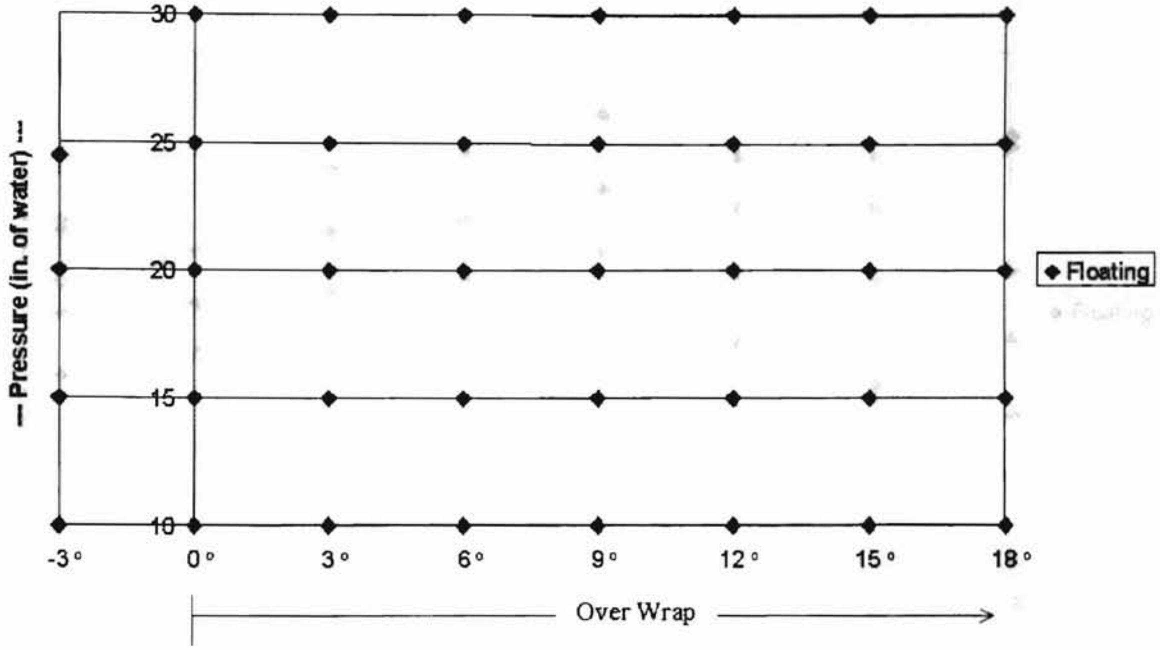


Figure 4.29 Effect of Gap-Pressure and Wrap-Angle on Buzz for Air-Turn Bar with 0.075" Hole Size 9 rows and Damper

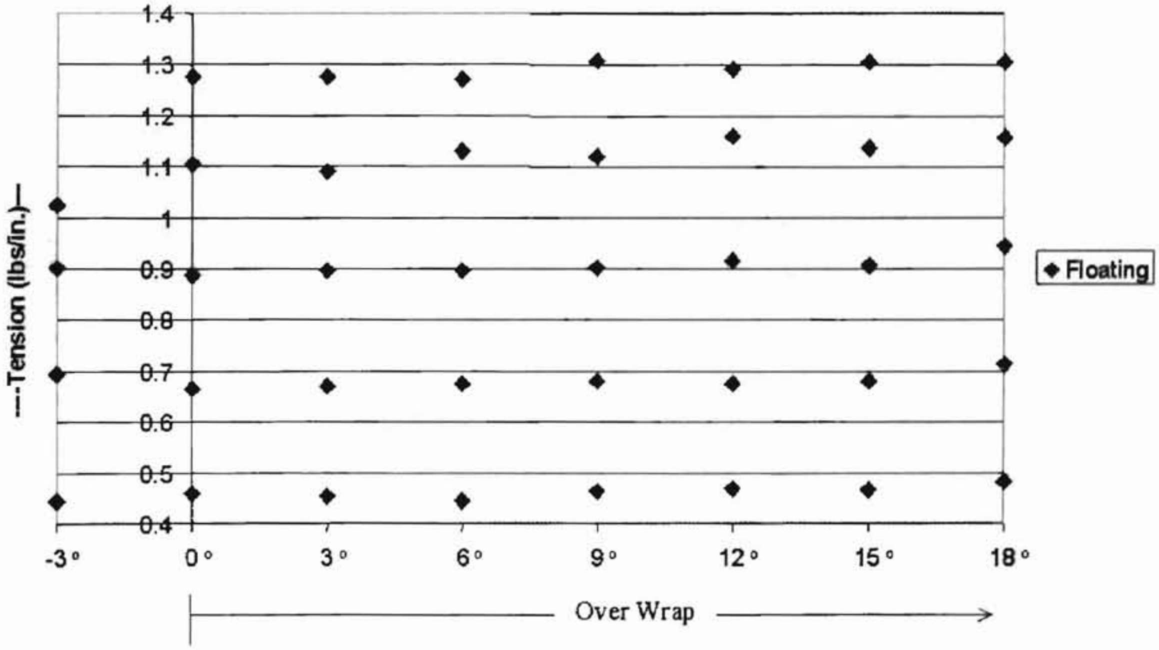


Figure 4.30 Effect of Tension and Wrap-Angle on Buzz for Air-Turn Bar with 0.075" Hole Size 9 rows and Damper

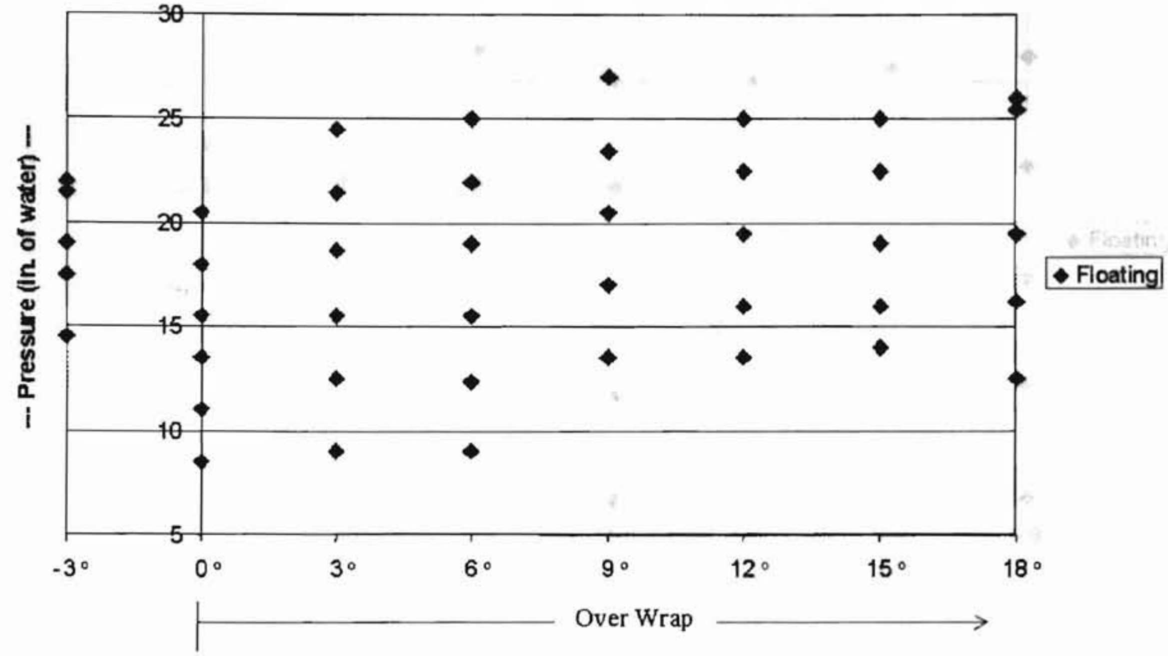


Figure 4.31 Effect of Gap-Pressure and Wrap-Angle on Buzz for Air-Turn Bar with 0.1" Hole Size 3 rows and Damper

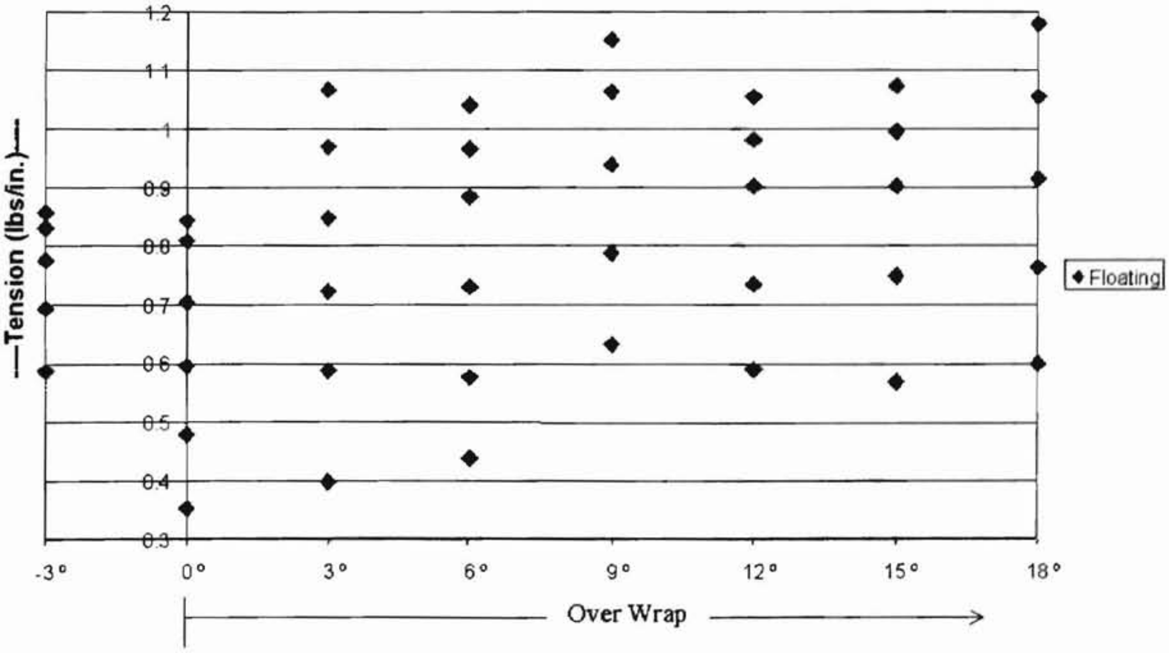


Figure 4.32 Effect of Tension and Wrap-Angle on Buzz for Air-Turn Bar with 0.1" Hole Size 3 rows and Damper

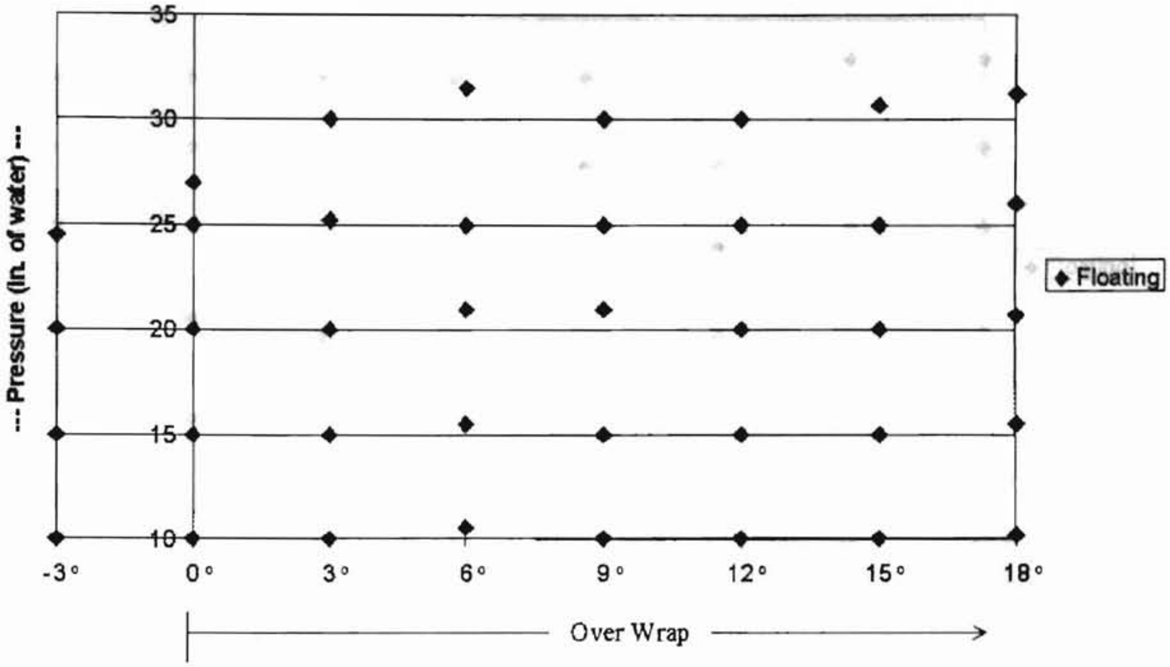


Figure 4.33 Effect of Pressure and Wrap-Angle on Buzz for Air-Turn Bar with 0.1" Hole Size 9 rows and Damper

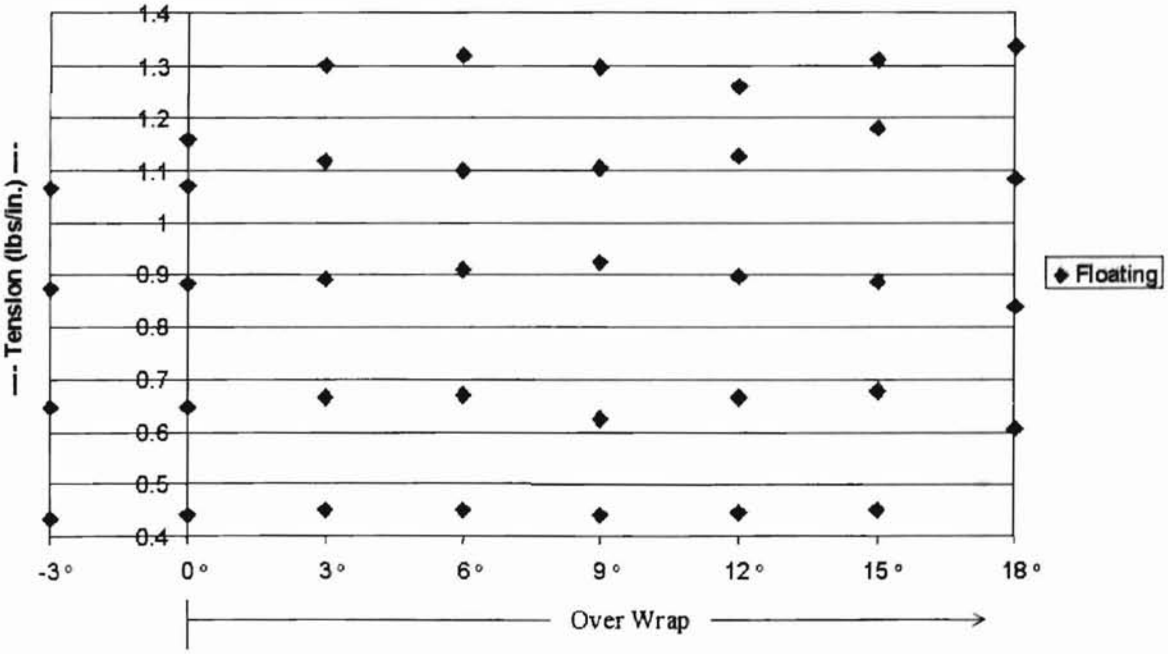


Figure 4.34 Effect of Tension and Wrap-Angle on Buzz for Air-Turn Bar with 0.1" Hole Size 9 rows and Damper

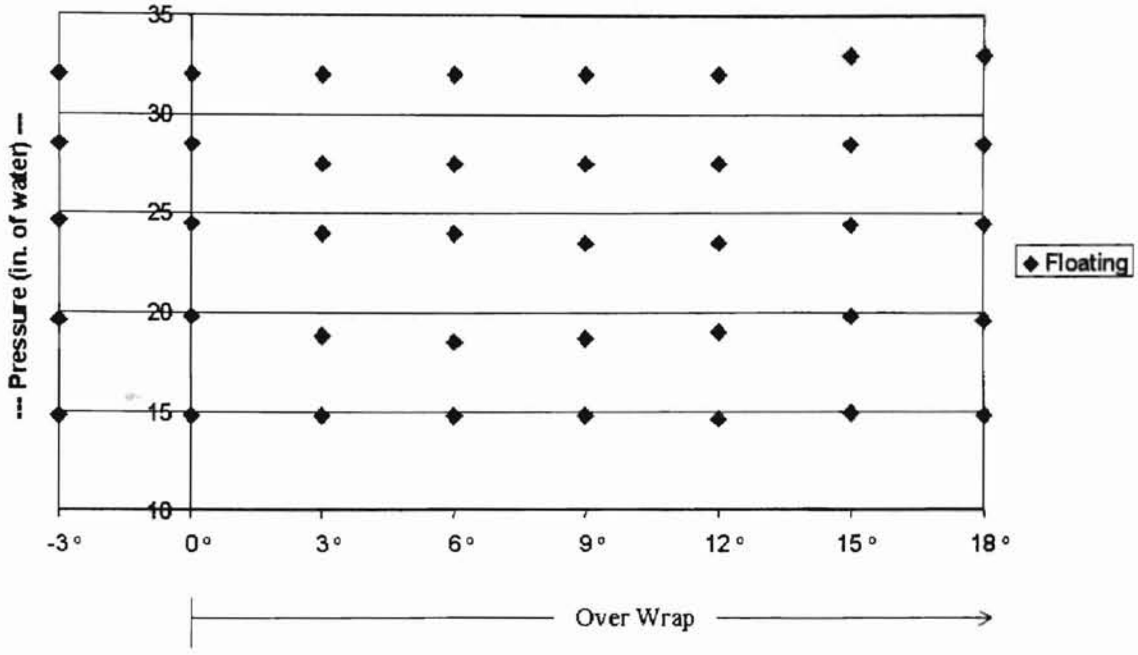


Figure 4.35 Effect of Gap-Pressure and Wrap-Angle on Buzz for Air-Turn Bar with 0.1" Hole Size 5 rows and Damper

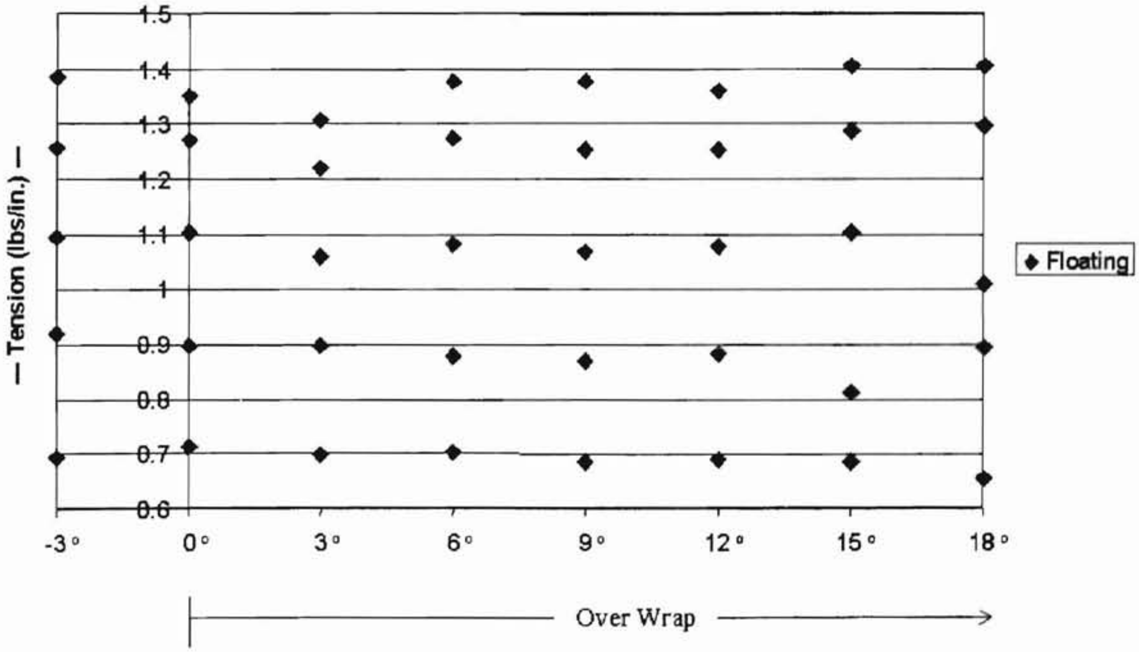


Figure 4.36 Effect of Tension and Wrap-Angle on Buzz for Air-Turn Bar with 0.1" Hole Size 5 rows and Damper

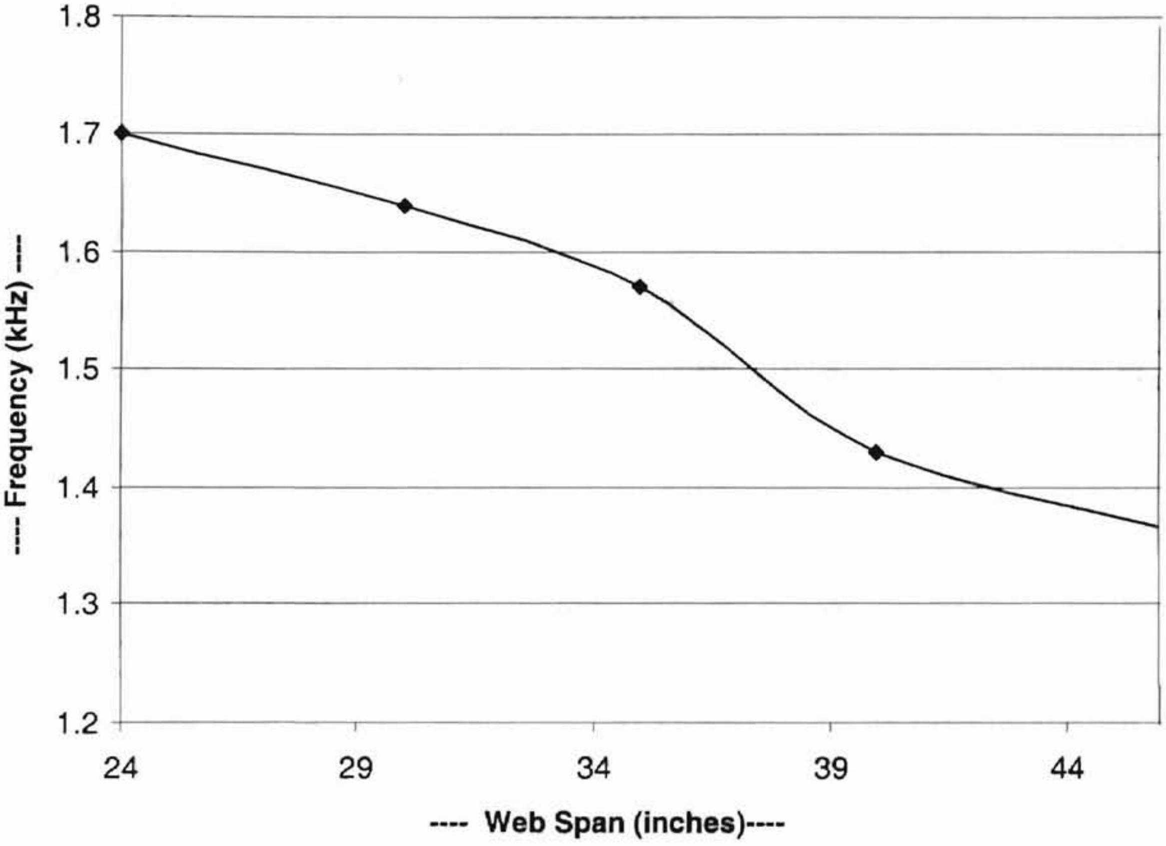


Figure 4.37 Effect of Web-Span on "buzz" at 10° of Over-Wrap and 30 (Inches of water) Pressure.

CHAPTER 5

SUMMARY AND CONCLUSIONS

Flutter and "buzz" of a web at an air-reverser were studied experimentally. Different modified air-turn bars were tested. The effect of web tension, length, pressure, holes distribution, holes size, web span and wrap angle on the flutter was examined. The following conclusions were obtained based on the experiments:

- Negative over-wrap (under-wrap) increases air consumption and risks touchdown because of air loss.
- Over-wrap angle is a very influential factor for buzz to occur. "Buzz" increases with decrease in over-wrap angle and is worst near zero over-wrap angles.
- There is always an increase in frequency and often an increase in amplitude of "buzz", with increase in web tension.
- Pressure increase tends to increase "buzz".
- There is a decrease in frequency with an increase in web span.
- Damping screen mounted at the point of departure of the web from the air-turn bar can significantly reduce the "buzz" in most of the over-wrapped webs, but air blown through the screen could cause touching.
- A sharp-edge separation notch adjacent to the last row of holes had no effect on the "buzz".

- Angled holes on the air-reverser have shown no changes in the results.
- With an angled-gap of 2°, between a damping plate and the web at the next, there is complete elimination of buzz over the entire range of wrap angles.
- Combination of damper-plate and smaller holes on the air-turn bar can completely eliminate buzz at all wrap angles.

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