ANALYSIS OF THE BINGHAM-WILLAMETTE NUCLEAR PUMP TEST LOOP

Prepared for

Bingham-Willamette Company

by

J. Paul Tullis

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INTRODUCTION

This report contains an analysis of the existing problems with the nuclear pump test loop at the Bingham-Willamette Company. The origin of the difficulty is identified and proposed modifications are suggested. The problem investigated was to find the source of and recommend modifications to eliminate the cyclic loading on the impeller shaft. Tests indicated that a cyclic loading was occurring at a frequency very near the shaft frequency of 1188 rpm (19.9 hz). The magnitude of the cyclic load was about 30 to 35 percent of the mean shaft load.

Two solutions to correct the existing difficulty are proposed. The first is a temporary low cost modification to enable resumption of tests at the earliest possible date. This recommendation will reduce the severity of the problem, but it is doubtful if it will be satisfactory as a permanent modification; especially for the tests on the larger pumps. The second recommendation involves a more extensive modification which will materially improve the hydraulic performance of the loop and should completely eliminate the objectionable cyclic loading on the impeller.

IDENTIFYING THE PROBLEM

The complete piping system, individual branches, junctions and suction manifold were investigated as possible sources of trouble. Following is a list of the possible sources of the problem and the author's judgement regarding them.

Problem: Can the "organ pipe effect" generate a 20 hz disturbance in the piping system?

Answer: (No) The 26-inch discharge pipe is too short to have a natural frequency as low as 20 hz. Its natural frequency for sound transmissions through water would be closer to 40 to 50 hz. The complete piping system would hardly be capable of generating and sustaining a resonant condition. The diameters, lengths and configurations of the piping vary too much.

Problem: Can the manifold from the 26-inch discharge line to the four venturies generate enough disturbance to create the cyclic loading on the impeller?

Answer: (No) This manifold is certainly generating considerable disturbance. The localized velocity through the elbows is probably approaching 80 to 90 fps due to contraction of the jet created by the entrance conditions. The magnitude of the resulting pressure fluctuations are proportional to V^N, where N is between 2.0 and 3.0. Even though considerable disturbance is generated at this location, the discharge manifold is not considered as the primary source of the problem for the following reasons. (1) Velocities of this magnitude (80 to 90 fps) are not uncommon in pipe systems and should not create unusually high turbulence. (2) The source of the disturbance is relatively far removed from the impeller so that considerable attenutation of the disturbances occurs in the piping system.

Problem: Is the suction manifold and the location of the butterfly valves creating the problem?

Answer: (Yes) The configuration and function of the suction manifold and control valves is such that the magnitude of the pressure disturbances generated at that location would be many times those generated at the discharge manifold. It is therefore felt that the primary souce of trouble lies in the configuration of the piping at the suction manifold.

Analysis of the Suction Manifold

Studying the existing flow pattern in the piping at the suction manifold reveals five sources of trouble.

1. The butterfly valves are closely coupled to the suction pipe. These valves are normally throttled to regulate the discharge. As a result two high velocity jets issue from each valve. These jets do not have time to dissipate before being deflected by the elbows and being directed into the suction pipe.

2. The jets from the elbows collide in the suction pipe at an angle of about 120 degrees. The relative velocity between the jets is therefore almost double the velocity through the butterfly valves. This relative velocity can be as high as 300 to 400 fps. The magnitude of the resulting pressure fluctuations being proportional to V^N , where N is between 2 and 3 can therefore be relatively high.

3. The confined space in the suction pipe increases the intensity of the pressure fluctuations. This is because the small separation zones surrounding the jets steepen the velocity gradient, increase the shear and increase the resulting pressure fluctuations.

4. The collision of the jets in the suction pipe causes additional instabilities in the flow. The resulting flow is more turbulent than a single jet at the same relative velocity.

5. There is not adequate distance between the suction manifold and the impeller to establish a reasonable flow pattern in the suction pipe.

PROPOSED SOLUTIONS

In developing ideas for modifying the pump loop, two requirements had to be considered. First, testing must be resumed in August of this year. This imposed a time limitation which would permit only minor alterations to the loop. Second, if the minor modifications would not adequately solve the problem, especially for the larger pump tests, what additional changes are needed?

Temporary Modification

This recommendation consists of moving the control valves about seven feet upstream, installing flow straighteners in the suction pipe and venturies, and flow dividers in the suction pipe. Moving the valves would be accomplished by cutting seven feet from each venturi and welding the sections into the lines below each valve. This change would not require any variation in the net length of the vertical or horizontal pipes. Figure 1 is a sketch of this proposed change. Details of the flow straighteners are included later in the report.

This scheme will improve the flow through the loop in several ways:

1. With about seven feet of pipe between the valves and the elbows, the velocity profile of the flow approaching the elbow will be fairly

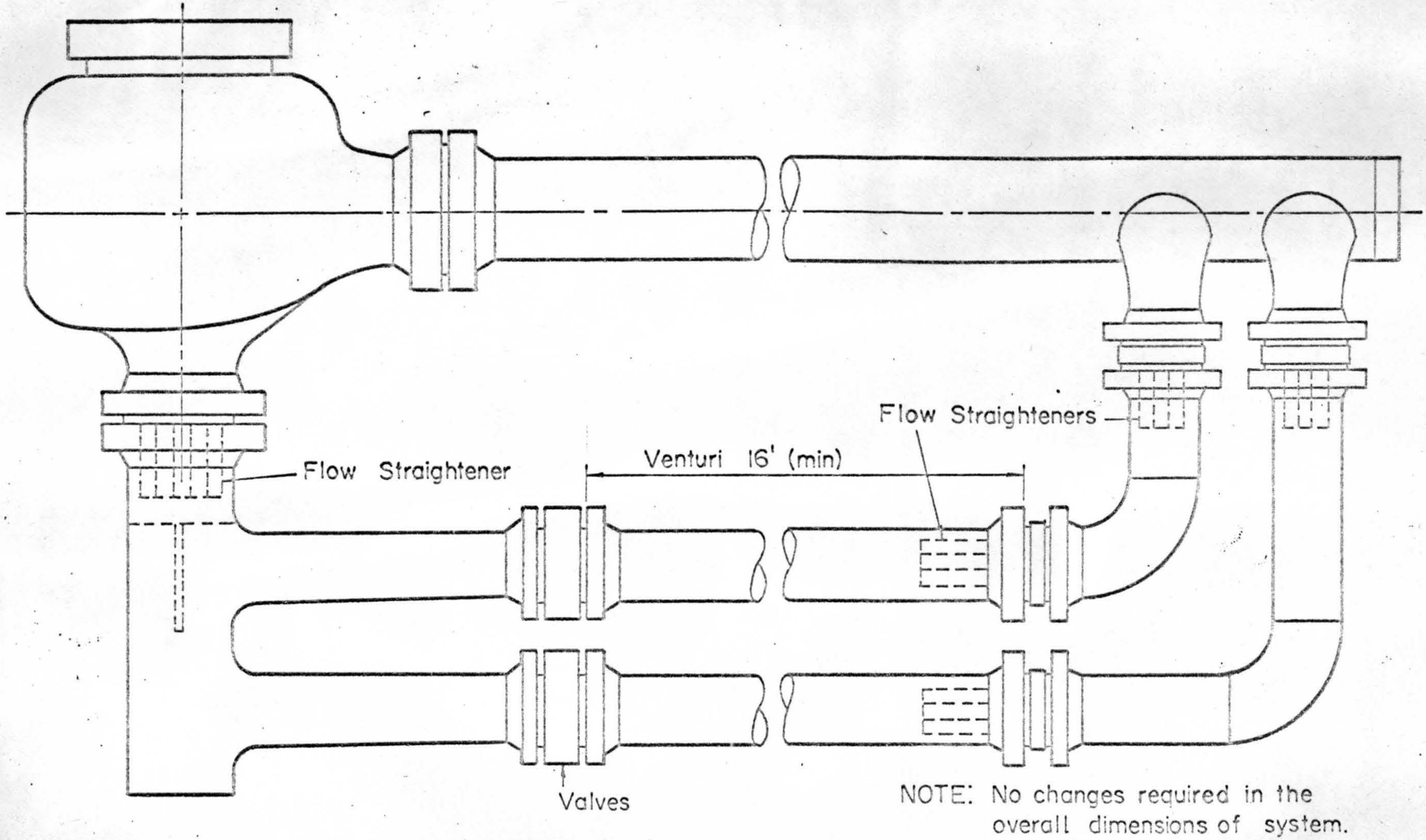


Figure 1. Schematic of proposed temporary modification.

uniform. The maximum velocity directed into the suction pipe will, therefore, be closer to the average pipe velocity (45 fps) rather than the jet velocity from the valves.

2. The maximum velocity in the system would be the jet velocity (rather than about two times that value). The turbulence caused by this high velocity would be generated far enough from the impeller that it would be attenuated before reaching the pump.

3. The flow dividers in the suction pipe isolate the discharge from each line. This eliminates the instability created by the colliding jets, eliminates the vortex which surely exists in the present setup and reduces the maximum relative velocity in the suction pipe.

4. With the maximum velocity in the suction pipe reduced to about one fourth, the magnitude of the pressure fluctuations generated in the suction pipe could correspondingly be reduced by something like 10 to 20 times.

This modification is not considered adequate as a permanent solution even though it should greatly reduce or possibly eliminate the objectionable cyclic loading on the impeller. The reasons are: First, without adding several feet to the height of the loop, the velocity profile approaching the impeller will be far from uniform. Such condition would not adequately represent the prototype installation. Second, even though the turbulence in the suction pipe should be significantly reduced, the energy dissipation is confined to such a small space that the resulting turbulence in the suction pipe will be higher than desirable and again would not simulate prototype conditions. Third, with so much turbulence and nonuniformity of the flow at the pump inlet, it is questionable whether a pressure reading near the inlet flange can be used to infer the pressure at the same flow rate in the prototype installation. In general, it is considered that although the system may operate free of damaging pressure fluctuations and vibrations, the experimental data obtained on the pump will be questionable because of the poor approach conditions to the pump impeller.

One other alternative for a temporary modification which was considered was placing the control valves in the vertical lines just below the elbows. This is not recommended because even under normal condition butterfly valves are very susceptible to leaf flutter and installing them at that location will intensify the problem. The flow will make two turns, each approximately 90 degrees just before it reaches the valves. At high discharges the nonuniform approach velocity can have velocities near 60 to 80 fps. This high velocity combined with the natural instability of the flow through the elbows creates a condition which could result in damage to the valves and generate objectionable disturbances in the loop.

Permanent Modification

This proposed modification involves a major change in the piping arrangement at the suction side of the pump. The pertinent features are shown on Figure 2. This system can be used without changing the overall height or length of the test loop. It consists of: (1) installing straightening vanes in the vertical leg of each venturi line, (2) placing turning vanes in the elbows upstream of #2 and #3 venturies and straightening vanes below the elbows in #1 and #4 venturi lines, (3) shortening the venturies to about 13 feet, (4) placing the valves immediately following the venturies, (5) using short length of 16-inch pipe below the valves which increases to 26-inch pipe about four feet in length, (6) the four

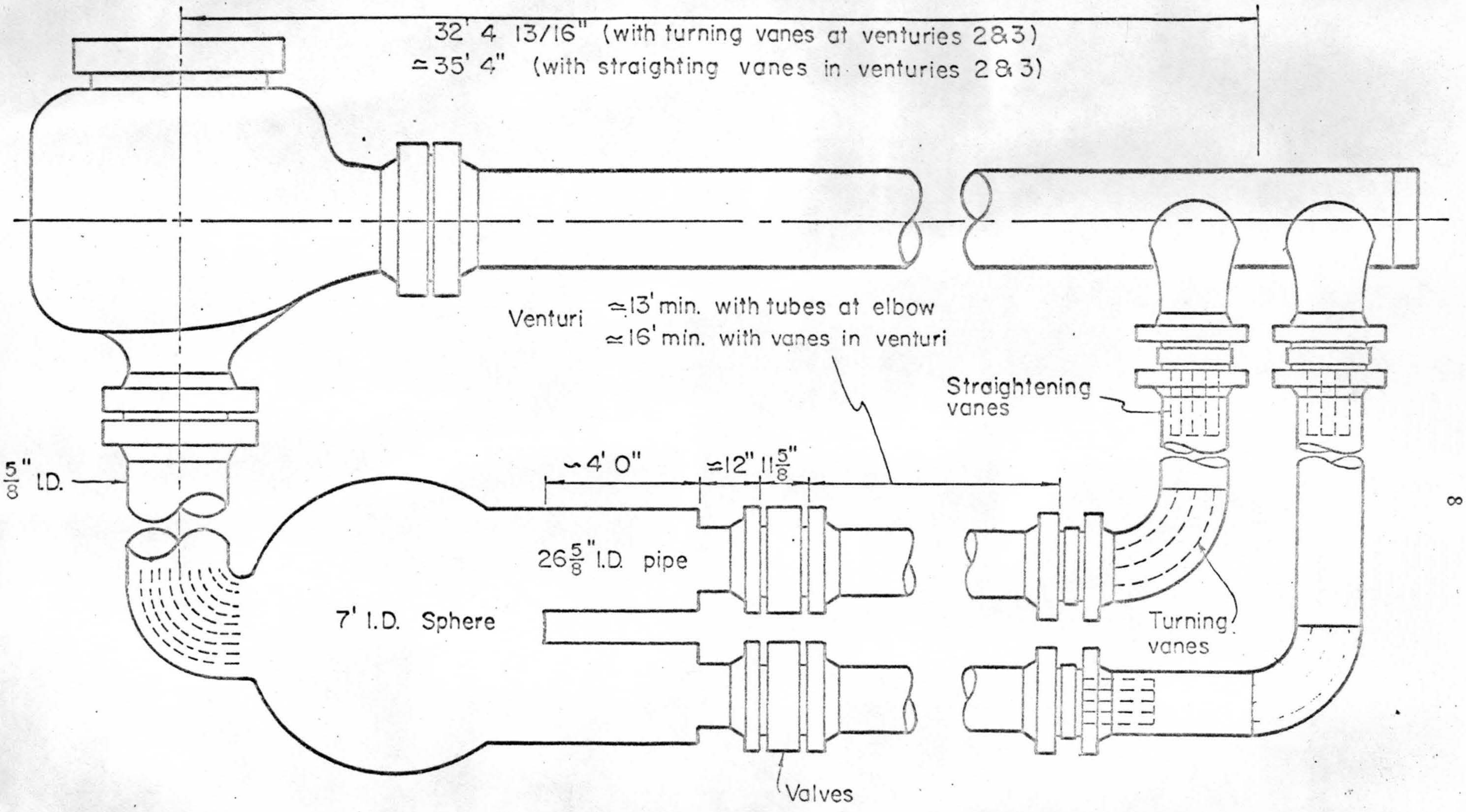


Figure 2. Schematic of proposed permanent modifications.

26-inch pipes discharge into a seven-foot ID sphere which directs the flow into the suction pipe, and (7) turning vanes in the elbow of the suction pipe.

The straightening vanes in the vertical legs of the venturi lines will help stabilize the flow before it enters the second elbow. The turning vanes in lines 2 and 3 are required to keep the total length of the loop unchanged. If straightening vanes are used below the elbows rather than the turning vanes as for lines 1 and 2, the length of the loop would have to be increased by about three feet.

With the turning and straightening vanes as suggested, the venturies can be reduced in length to 13 feet and still meet ASME standards for approach conditions. This will allow adequate length downstream for installation of a manifold which will greatly improve the overall performance of the loop and eliminate the cyclic loading problem.

The following discussion will attempt to explain the reasons for selecting the recommended piping configuration. The two guiding criteria utilized in developing a permanent solution were (1) the need for uniform flow in the suction pipe, and (2) minimize the disturbances in the suction manifold. The first requirement is satisfied by removing the energy dissipation process from the suction pipe, by streamlining the entrance from the sphere and using the turning vanes in the elbow.

The design to minimize the turbulence in the suction pipe and manifold was based on the following principles:

1. Reduce the velocities in the manifold.
2. Allow the turbulence generation to occur remote from the suction pipe.

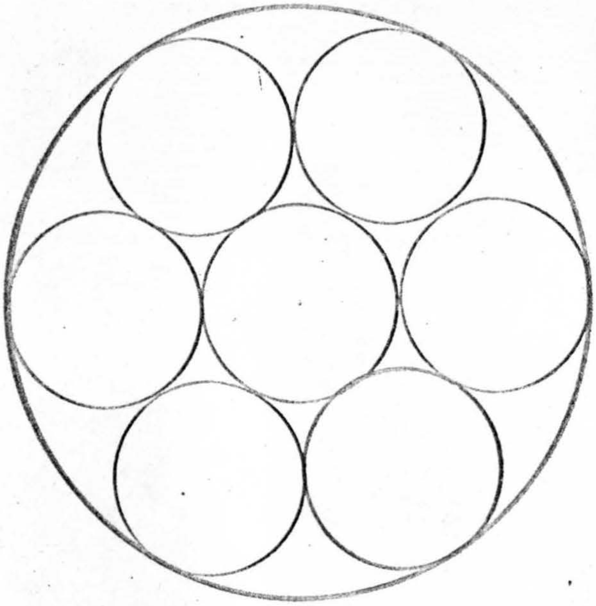
3. Minimize the turbulence created by the high velocity jets from the valves by allowing them to discharge into an enlarged pipe.
4. A water jet will dissipate (creating a uniform velocity profile across the pipe) in a shorter distance if it is completely surrounded by water.
5. Contracting flows suppress turbulence.

With the above five principles in mind, a description of how the proposed system improves the flow is given. As the flow leaves the butterfly valves the short length of 16-inch pipe directs the jets into the 26-inch pipe so that the jets are completely surrounded by water. By the time the water enters the seven-foot diameter sphere the jets are well dissipated and the velocity greatly reduced. The maximum pressure fluctuations will occur in the 26-inch pipe near the junction with the sphere. The flow from the four lines enters the sphere symmetrically and is accelerated and contracted into the suction pipe. The rounded entrance and the turning vanes in the elbow further suppress the turbulence and create a uniform velocity profile in the suction pipe.

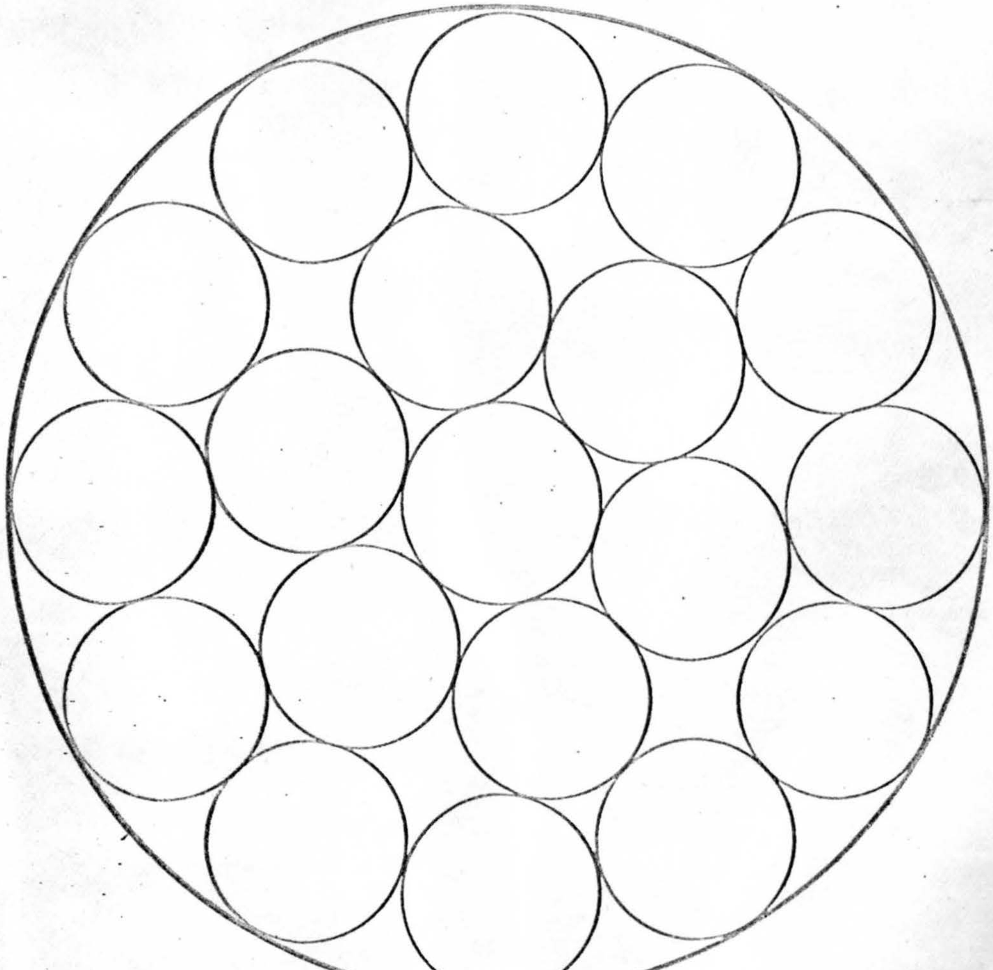
Using the 26-inch pipe below the valves allows a seven-foot sphere to be used but gives the same effect as a sphere about 11 foot in diameter. If 16-inch pipe were used below the valve, an eight-foot sphere would be required and the length of the loop should be increased about two feet to provide the same benefits.

Turning and Straightening Vanes

Based on optimum hydraulic performance and the desirability of installing turning vanes in some of the elbows, a honeycomb fabricated from short lengths of pipe is recommended. Figure 3 shows a cross section of a possible layout using $5\frac{1}{4}$-inch O.D. pipe. The size and



Cross-section of flow straighteners for 16" pipe



Cross-section of flow straighteners for 26" pipe

Figure 3. Details of flow straighteners typical layout of pipes for flow straighteners.

number would be dependent on what was commercially available. The bundles could be made very rigid by welding the pipes together as each pipe is stacked into the bundle. The bundles could then be securely welded into the pipes.

Fabricating and installing the turning vanes would be somewhat more difficult. The pipes would be individually cut to length and bent on the proper radius. The tubes would be nestled in a form and welded together individually as they are stacked. The resulting bundle could then be slipped into the elbow. For the two venturi lines this would necessitate cutting the pipe where it meets with the elbows. Even though this type of turning vane is more expensive than straight vanes, the savings in not lengthening the loop and rotating it in the building should justify their use.

To increase the strength and stiffness of the vanes, it is suggested that stainless steel be considered. Properly designed, fabricated and installed, this type of flow straightener will be structurally sound. Its main advantage is that it is the optimum hydraulic design for minimizing disturbances generated by the vane itself and minimizing the local velocity since less material is required.