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AN ACOUSTIC CHAR FLOW MONITOR FOR THE BI-GAS PILOT PLANT

MASTER

by

P. D. Roach and A. C. Raptis

Components Technology Division
Argonne National Laboratory
Argonne, Illinois 60439

Technical Memorandum No. 08

July 1979

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ABSTRACT

The BI-GAS coal gasification pilot plant at Homer City, PA has an urgent need for monitoring char flow to the gasifier. An undetected flow stoppage can very quickly cause a dangerous temperature excursion in the gasifier. At the request of BI-GAS, the Argonne National Laboratory (ANL) has developed and installed acoustic monitors which will give rapid indication of blockages or other flow perturbations in the char lines. These monitors use a high temperature microphone, developed at ANL, for measuring the acoustic attenuation caused by the presence of char in the line. Such a measurement gives a sensitive indication of the amount of char flowing in the line and can be used for both process control and rapid detection of blockages.

1.0 INTRODUCTION

The BI-GAS coal conversion process is being developed by Bituminous Coal Research, Inc. at its pilot plant in Homer City, PA. The process involves two-stage high pressure coal gasification in an entrained bed type of reactor, shown schematically in Fig. 1. Powdered coal is fed to an initial (upper) stage where it is devolatilized and partly gasified as it contacts the hot gases rising from the lower stage. The gas and char (partly reacted coal) are separated in a char cyclone and the char is reintroduced into the gasifier in the lower stage. In this stage, the char reacts with steam and oxygen under much hotter conditions (1370° - 1650°C, 2500° - 3000°F). The residue, or slag, is molten at this temperature and flows to the water cooled quench zone, while the hot gases rise to the upper section of the gasifier. After passing through the char cyclone, the gases go to a shift reactor and fluidized bed methanator to produce a high BTU pipeline quality gas.

The instrumentation needs at the BI-GAS plant are fairly typical of those throughout the coal conversion field. In particular, flow monitors are needed that can handle the multiphase process streams. These streams are frequently at high pressure and high temperature and are very erosive. Available flowmeters are usually not able to withstand such a hostile environment.

Of particular concern at the BI-GAS pilot plant is monitoring the char flow. Blockage of the char feed lines between the char cyclone and the char burners has been a recurrent problem. The char first drops approximately 16 meters by gravity feed from the cyclone to a steam eductor where high pressure steam is added to the char. The char and steam then move horizontally about 3 meters to the nozzle of the char burner. Blockage of the char in either the vertical or horizontal section can cause a very serious perturbation of the gasifier operation and can quickly lead to a hazardous temperature excursion in the gasifier.[1]

The safety aspects of this problem made the need for a flow monitor quite urgent, but no commercially available unit was known that could do the job.[2] The design operating conditions in the char line are temperature of 430°C (800°F) and pressure of 11.4 MPa (1650 psi). The char particles are quite abrasive and also tend to plug orifices and to foul moving parts. Because of these difficulties, BI-GAS requested the assistance of Argonne in developing a suitable flow monitor. The group at ANL which has responsibility for instrumentation for coal conversion plants suggested several possible solutions. The acoustic monitor described in this paper was chosen as being the most promising approach, especially in view of the urgency.

2.0 DESIGN CONCEPT

Based on preliminary pilot plant measurements with no char flowing[3], it was evident that the steam eductor is a major source of acoustic noise. A microphone in the location shown in Fig. 1 produced a strong, broad-band signal associated with the steam flow. This meant that the presence of char could be judged in two different ways: first, by looking at the reduction of the steam signal caused by scattering from the char particles,[4] and second, by looking at noise added by the char flow (caused by impingement of particles on the pipe and microphone).[5]

The combination of a relatively streamlined geometry (to minimize flow obstruction and microphone erosion) and a large steam signal strongly favors the first mode. The second mode would be favored with a geometry that caused more particle impingement on the microphone or in a situation with much less background noise. The first mode dominates in the present situation and forms the basis for understanding the observed data.

In effect, the geometry in the char line allows us to make an attenuation measurement on the char. The steam eductor serves as a constant broadband noise source and the pipe section between it and the microphone is the attenuation path. The presence of the char particles will cause absorption and scattering of the acoustic energy generated by the steam eductor, giving a decrease in the observed microphone signal. The amount of this decrease will be an indication of the amount of char present in the line. Thus, the apparatus will not only indicate positively whether char is flowing or not, but also will give an indication of the amount that is flowing. This indication will relate only to the char density, however. An additional measure of the char velocity is necessary to obtain mass flow rate.

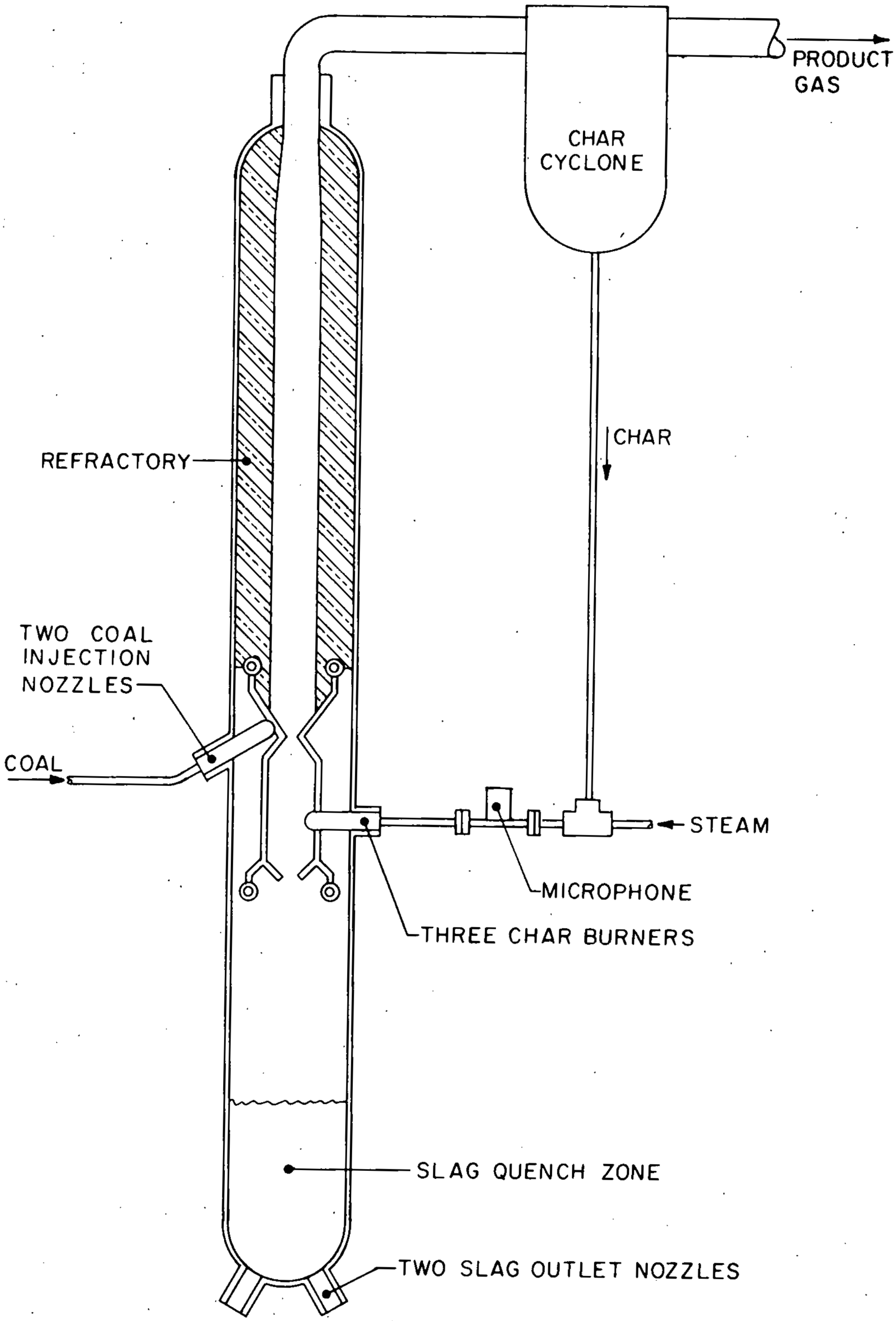

Fig. 1 Schematic Diagram of BI-GAS Reactor

3.0 INSTRUMENTATION

The microphone chosen for this application is a rugged high-temperature unit developed in the Components Technology Division of ANL.[6] As shown in Fig. 2, it uses two identical plates of lithium niobate arranged back-to-back with respect to their piezoelectric polarities. This makes the microphone sensitive to pressure changes on the faces but it is relatively insensitive to vibration of the device as a whole. This design means the microphone cannot be clamped to the outside of the pipe but must be immersed in the flow. Fortunately, this microphone is well suited to withstand the severe process conditions, since it is completely encased in type 304 stainless steel and is capable of operating at temperatures up to 650°C (1200°F) and pressures up to 14 MPa (2000 psi). The frequency response of the microphone is fairly constant from 100 Hz to 50 kHz, but is virtually nil above 100 kHz. The absolute sensitivity of the microphone (calibrated in water) is approximately 1.2×10^{-2} pC/Pa.

Microphones have been installed in the horizontal sections of the three identical char feed lines. Figure 3 shows the microphone housing before installation of the microphone. The char line is nominal 1 1/4 inch schedule 160 stainless steel pipe, and connections are made with 2-inch Grayloc fittings.[7] The microphone housing is at the center of this section of pipe and consists of a 2-inch tee with a Grayloc hub welded to the branch. The microphone is supported from a mating hub that forms a demountable seal. A 2.22 cm (0.875 inch) hole in the wall of the char line allows the microphone to sense pressure fluctuations in the process stream but causes minimal disturbance to the flow and negligible erosion of the microphone.

Figure 4 shows the microphone as it is supported from the blind Grayloc hub. This support is designed to position the lower edge of the microphone flush with the inner surface of the char line, in the hole that was machined in the pipe wall. The signal lead for the microphone passes through the Conax compression seal[8] as shown. The fitting uses a lava sealant to seal against the high temperature, high pressure gas in the char line.

For the initial studies, the microphone signal was first amplified in a remote charge converter located near the microphone. The amplified signal was then recorded and analyzed in the BI-GAS control room using the configuration shown in Fig. 5. The Real Time Analyzer and Ensemble Averager display the frequency spectrum of the microphone signal, while the tape recorder saves the data signal for later analysis. A simplified frequency analysis of the signal can be made with the bandpass filter and RMS voltmeter. With this latter technique, it is easy to measure signal power in selected frequency bands.

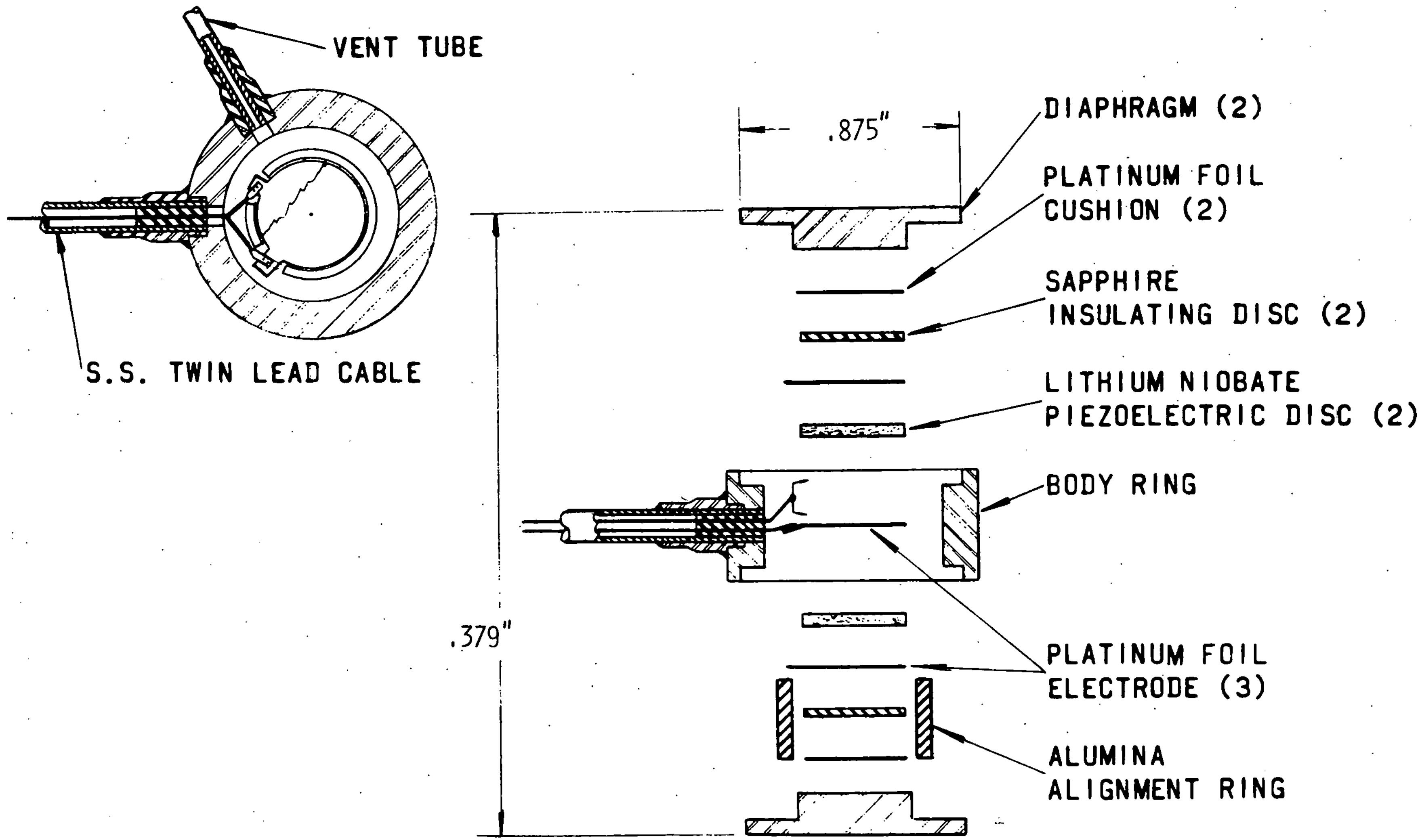

Fig. 2 Construction Details of High-Temperature Microphone

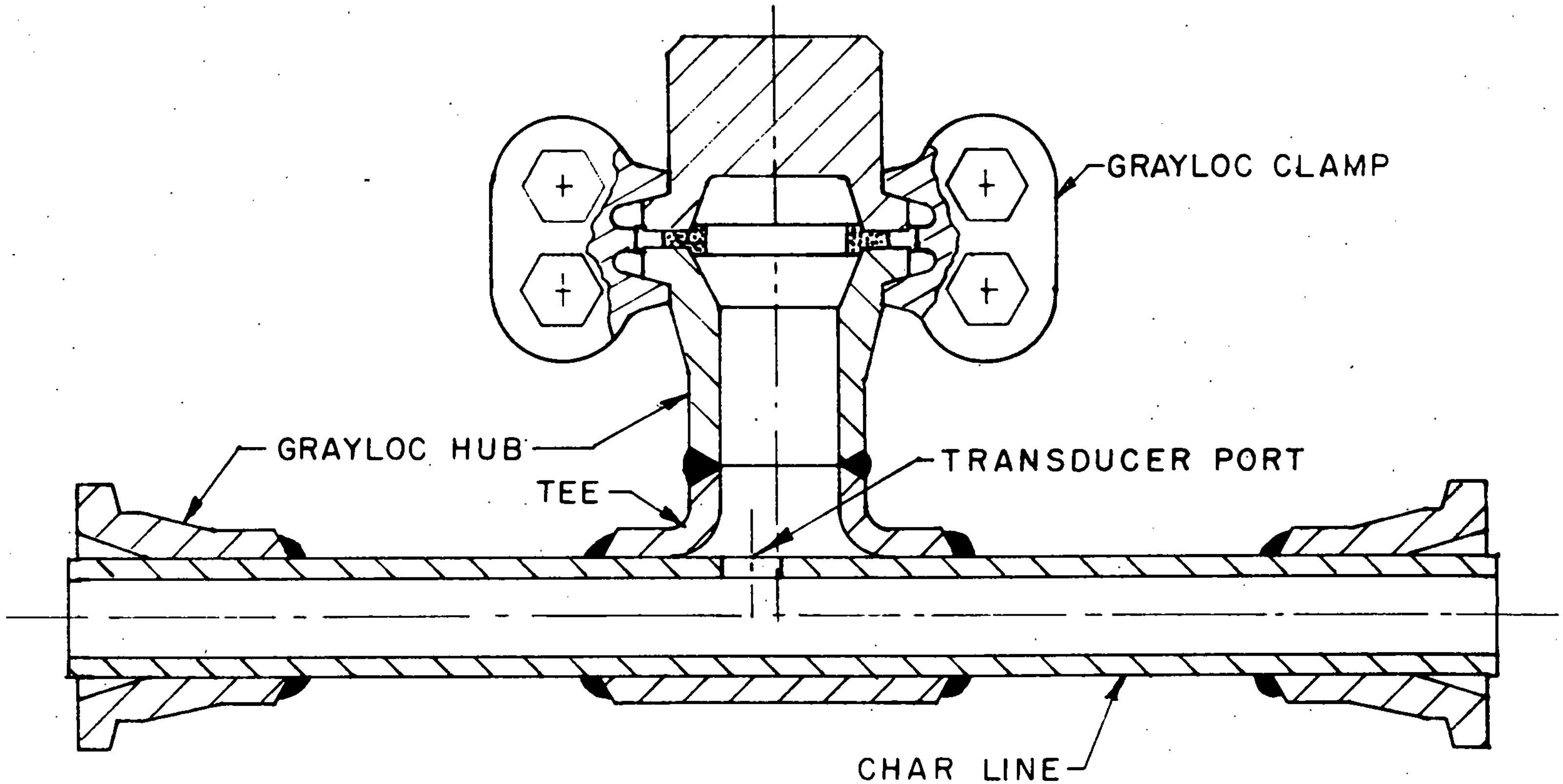

Fig. 3 Microphone Housing for BI-GAS Char Line

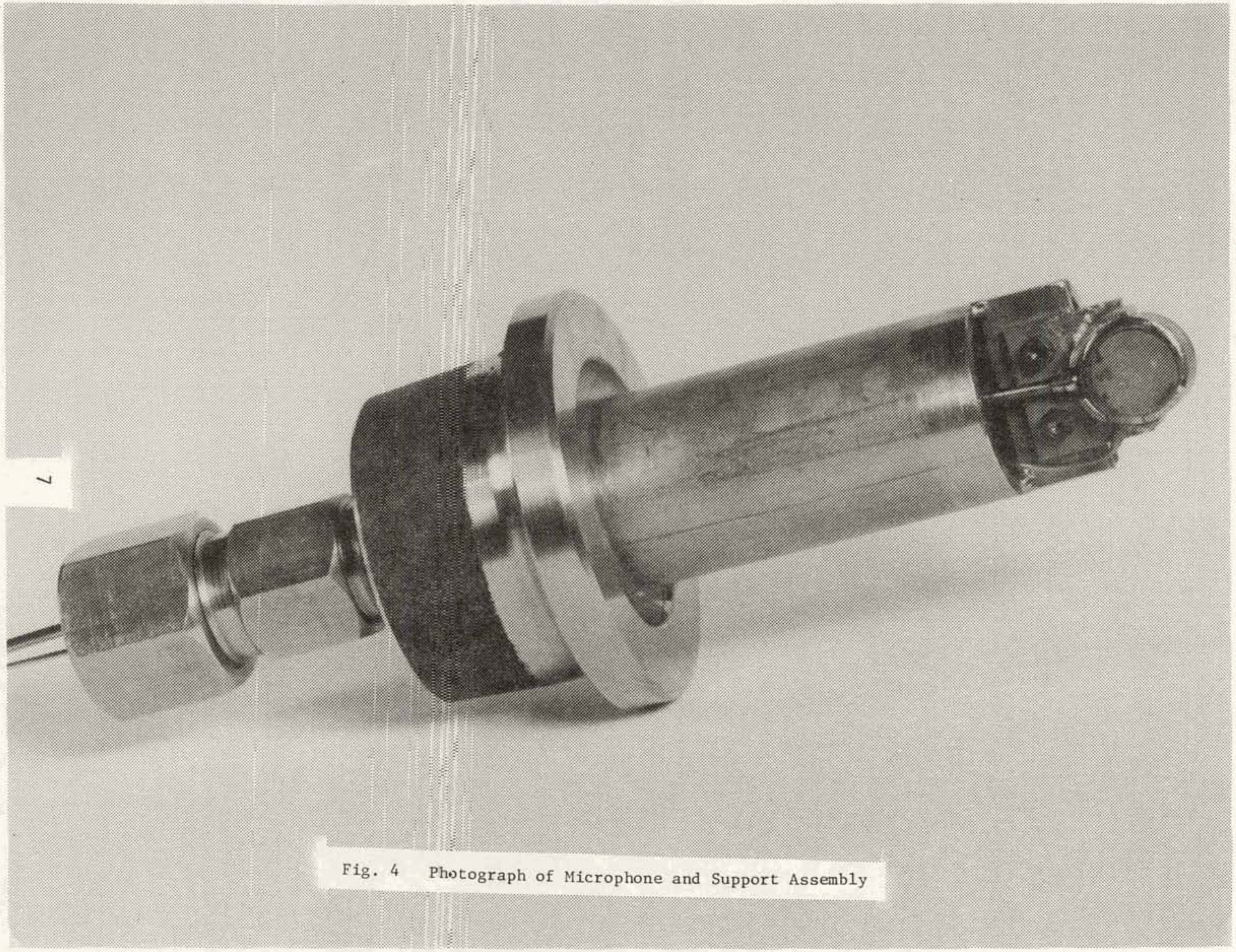

Fig. 4 Photograph of Microphone and Support Assembly

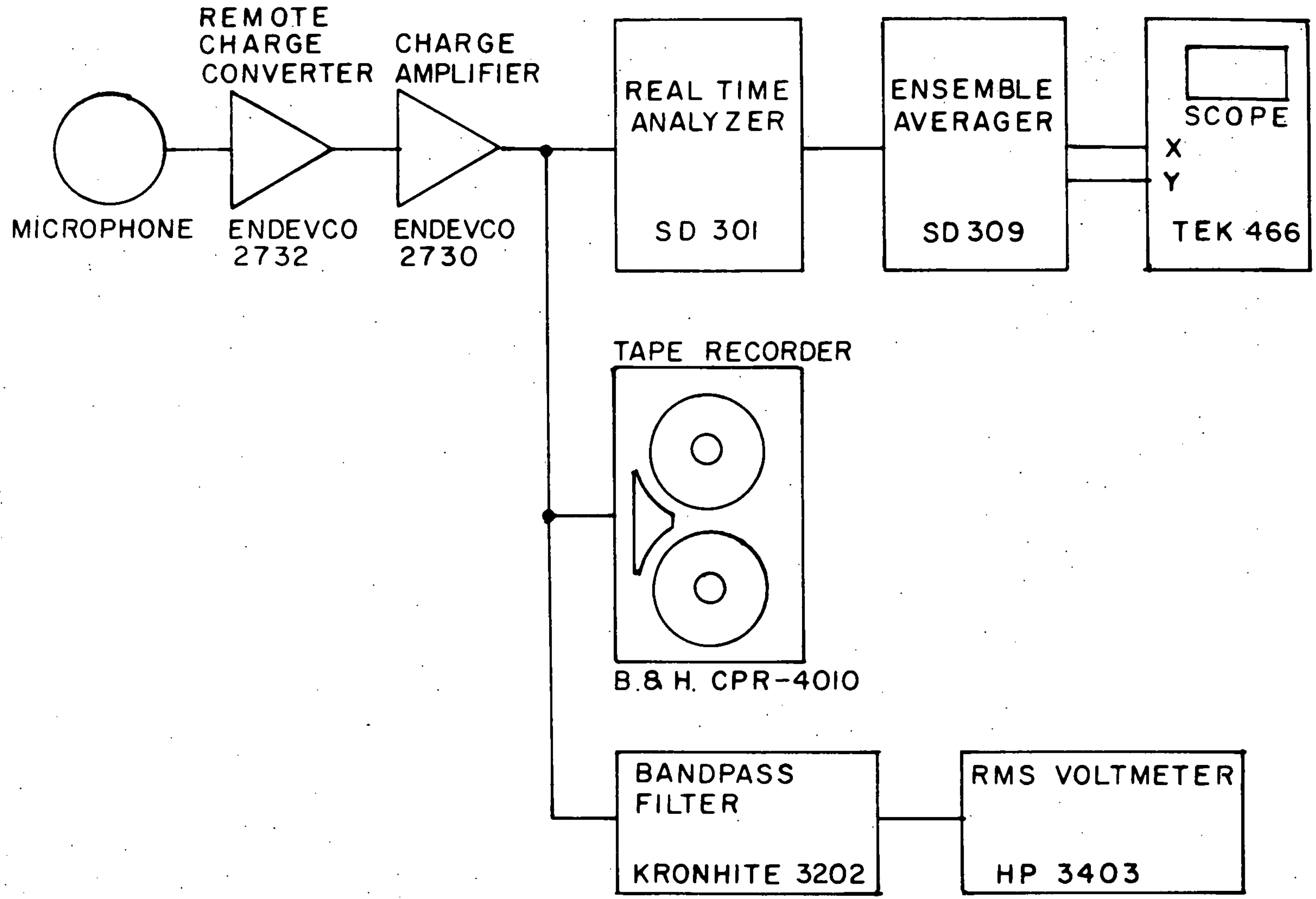

Fig. 5 Electronics for Microphone Signal Analysis

4.0 DATA

The spectral analysis of the microphone signal is shown in Fig. 6, for various rates of char flow. In each figure, the upper trace is the spectrum of the signal when only steam was flowing in the line. The lower trace is the spectrum taken when char was also flowing. The exact amount of char was not known but the relative flow rate was inferred from valve openings and readings of differential pressure instruments. Figures 6a, 6b and 6c correspond to low, moderate and high relative flow rates, respectively. The lower trace in Fig. 6d shows the spectrum with no char and no steam flowing. All the spectra were taken with an analysis bandwidth of 300 Hz. The reference level at 0 dB corresponds to 1.0 v RMS at the output of the remote charge converter.

The spectrum of the steam-only signal clearly shows that the acoustic signal (noise) from the steam eductor is quite strong and rather uniformly distributed over the frequency range 0 - 50 kHz. As char is added to the line, the microphone signal becomes much smaller, with the greatest decrease at the highest frequencies. The signal is reduced below the level of the analyzer noise for the upper frequencies and its spectrum is not apparent, but it is evident that the signal loss increases with both frequency and char concentration. At the lowest frequencies (below 1 kHz), the signal with char flowing is somewhat higher than the steam-only signal. This is evidence that impingement noise caused by the flowing char is a significant part of the acoustic signal in this frequency band.

The change in the microphone signal which we observe as char is added to the line is consistent with the attenuation model which was discussed in Section 2. In this case, the char is causing an attenuation that is roughly proportional to frequency and to char concentration. The frequency dependence appears to be essentially linear but the concentration dependence cannot be determined without a calibration. All of the data taken so far shows that the attenuation is a monotonically increasing function of the char concentration in the line.

Based on this data, it is clear that we can easily distinguish between flow and no-flow of the char. Moreover, it should be possible to develop a measure that is directly related to the actual char concentration. This measure would be based on the relative attenuation at high and low frequencies and thus would not be dependent on absolute measurement of signal level. For example, the ratio of signal levels in the frequency bands near 1 kHz and 10 kHz will be a monotonic function of char concentration, and could be used (after calibration) as a char concentration (density) meter.

5.0 FLOW MONITOR DESIGN

An instrument to process the microphone signal and provide both the flow/no-flow indication and the char density indication has been designed along the lines discussed above. The block diagram for this instrument is shown in Fig. 7. The microphone signal is first amplified in an external charge amplifier and then is sent to the flow monitor where it is analyzed into three different frequency bands by bandpass filters. The RMS detectors

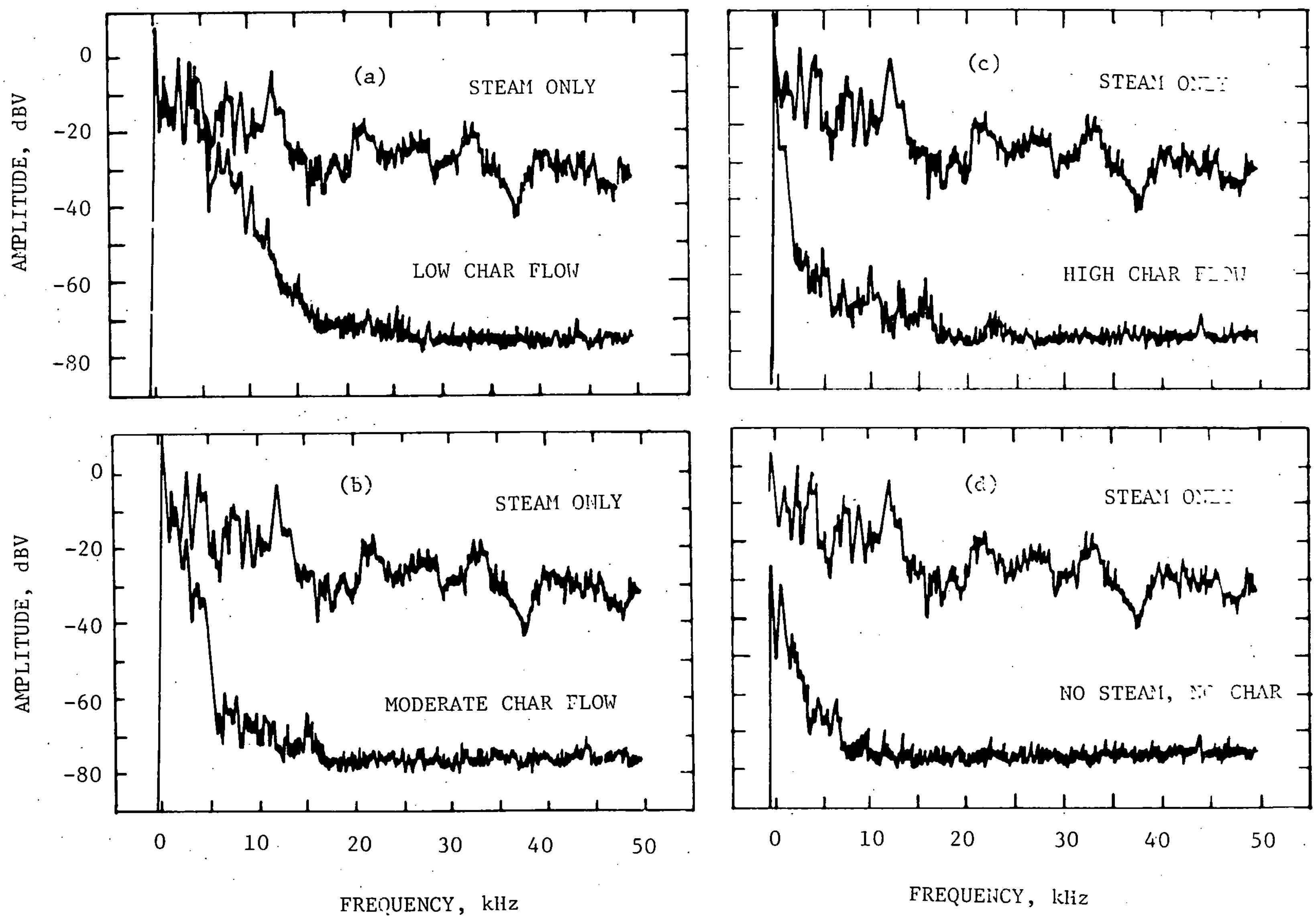

Fig. 6 Spectral Analysis of Microphone Signal

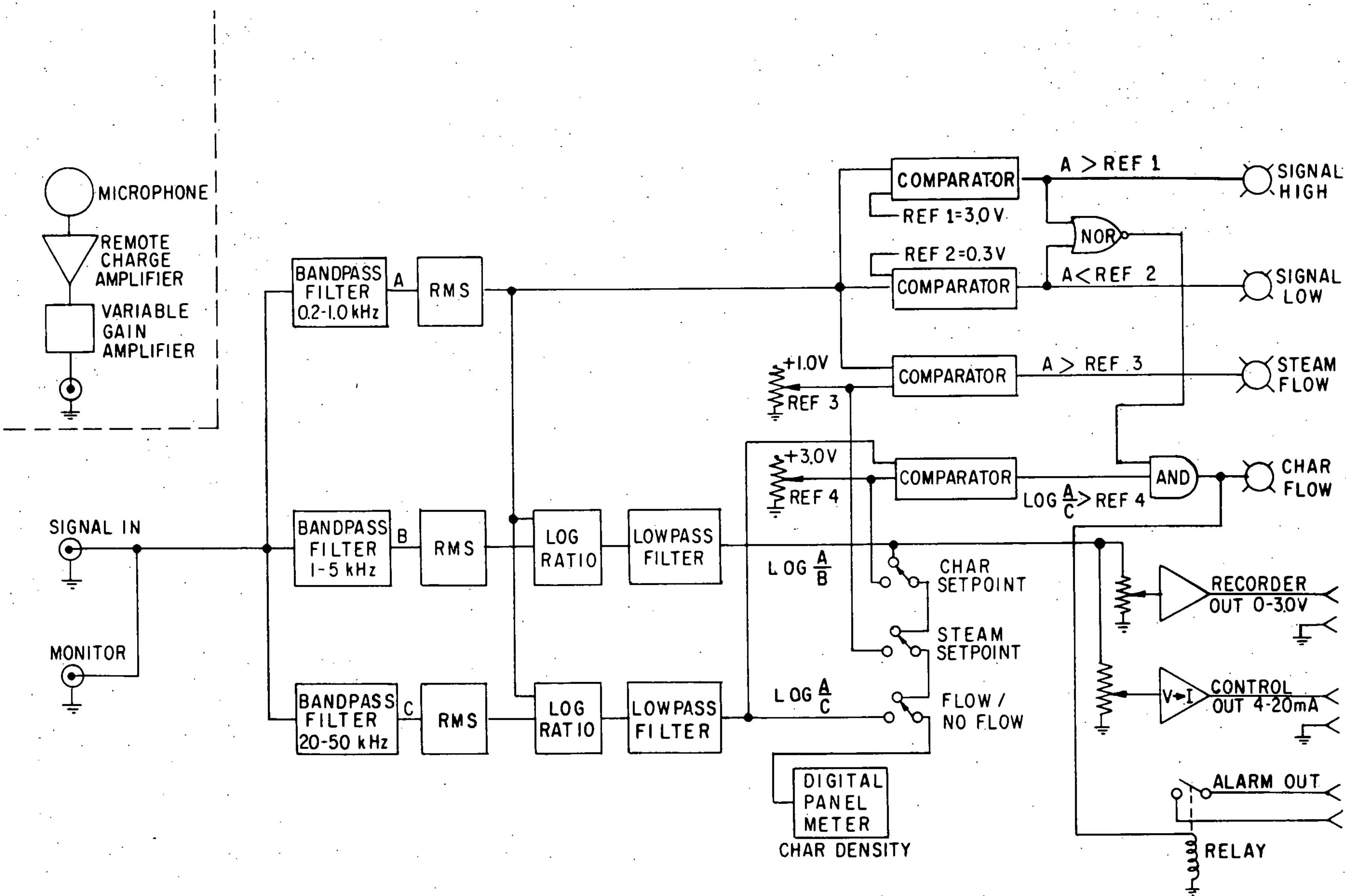

Fig. 7 Block Diagram of Flow Monitor

and LOG RATIO converters generate a DC voltage proportional to the log of the ratios of the amplitudes in the frequency bands. The A signal is the lowest frequency component and is least attenuated by the char, so this signal is taken as the amplitude reference. The other two signals are then normalized to this reference with the result being fed to a voltmeter for the intermediate band and to a voltage comparator for the high frequency band. The high frequencies are most sensitive to the presence of char and this signal (signal C) is used for the flow/no-flow indication. Whenever the high frequency signal drops below a certain level relative to the low frequency band, the CHAR FLOW light turns on.

The intermediate frequency band (signal B) is less sensitive to the presence of char but gives a useable signal over a wider range of char density. This band is used to give a continuous indication of char density. It is expected that the signal derived from this intermediate frequency band can be calibrated in terms of actual mass density of char in the pipe. Then if flow velocity can be determined, the mass flow rate of char would be obtained.

Other features which have been incorporated into the flow monitor permit external use of its signals and provide indications of proper operation. Both voltage and current outputs are provided for driving a recorder or a process control system with the char density signal. These outputs have adjustable gain and time constant. The flow/no-flow signal is used to provide a contact closure for an external alarm system. But the contacts will close only if the unit has power and the input signal is within specified bounds. This guards against misleading CHAR FLOW indications that might be based on signals outside the range of accuracy of the circuit.

Front panel indicators show if the input signal is too large or small and the panel meter may be used to check various circuit voltages. But for comprehensive testing of circuit function, it is necessary to inject known test signals. For this purpose a separate test module has been constructed. This module provides four different signals designed to confirm proper operation of all of the flow monitor circuits. In this way, each flow monitor can be quickly checked out, either as part of a routine maintenance procedure or when the operator suspects a malfunction. The finished Flow Monitor is shown in Fig. 8. Three identical modules are shown, one for each of the three char feed legs. Also shown is the module used for testing the flow monitor.

6.0 RESULTS

The results from the use of the flow monitor at BI-GAS have been quite satisfactory. The instrument has given rapid and clear indications whenever char flow has started or stopped. In addition, the char density signal has responded well to the variations in char flow as the control valve settings have changed. But the flow monitor indication has not always agreed well with other instruments, primarily differential pressure indicators. This may be due to the greater sensitivity and faster response of the flow monitor, but may also be related to the fact that the differential pressure instruments are quite sensitive to other factors, such as gas composition, gas temperature and purge gas flow. As more experience is gained with the flow monitor, it is expected that the discrepancies will be resolved.

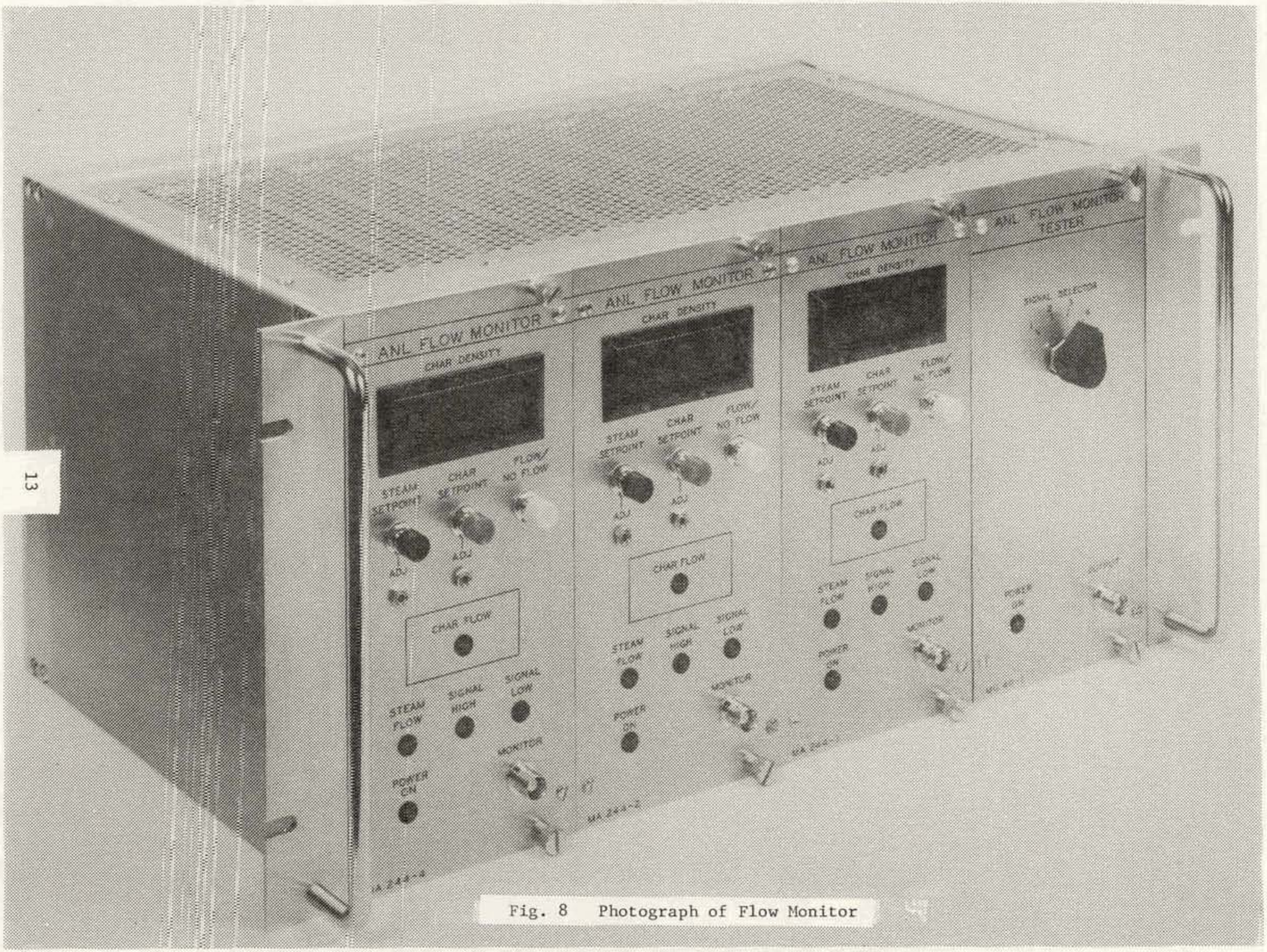

Fig. 8 Photograph of Flow Monitor

An example of the output of the flow monitor is shown in Fig. 9. This is a recording of the char density signal that was made during BI-GAS test G7-A on February 24, 1979. At 2245 hours, the char line plugged and caused a shutdown of the char burner (marked "CLOSE VALVE" on record). At this time, steam flow continued but was diverted by the plug and flowed up the char leg. The operator promptly closed a valve in the char leg, thus forcing steam flow back down along the proper path to the burner and dislodging the plug.

At 2256 hours the char burner was relit and char flow resumed (marked "OPEN VALVE" on record). It is observed that char flow is somewhat less stable at this time. This is speculated to be the result of steam flowing up the char leg for a short time during the shutdown. The steam condensed on the char, causing the char to clump and to flow poorly when the valve was opened again.

The sensitivity and speed of response of the flow monitor is clearly seen in Fig. 9. Even though the char density signal is uncalibrated, it provides valuable information to the plant operator. Stability of the flow is easily judged and the char density signal allows the operator to know when a previously used flow rate has been achieved.

Experience with the acoustic flow monitor has been sufficiently encouraging that BI-GAS is considering using the device to control oxygen feed to the lower stage of the gasifier. If this can be done reliably, the supplemental fuel gas feed to this stage can be eliminated, thereby achieving a major milestone for the plant. In the past, the fuel gas has been added to prevent a dangerous oxygen-rich condition from occurring in case of an undetected loss of char feed. But if oxygen flow can be closely matched to char flow, then the fuel gas is no longer needed. The acoustic flow monitor is currently the most promising device for providing the necessary char flow signal.

7.0 FUTURE PLANS

Application of the acoustic flow monitor to the two coal feed lines to the BI-GAS gasifier is being considered. The coal lines are a different size from the char lines and the acoustic properties of the particles and the carrier gas are somewhat different. But the acoustic technique is still valid and is expected to work well in this application.

Since no calibration has been performed on the char density signal, it is only an indication of relative char density or flow. This is adequate for maintaining steady flow or for establishing a previously used flow. But calibration will permit optimization of the gasifier operation by allowing an accurate balance to be made between steam, oxygen and char flow rates. It is for this reason that plans are being made to calibrate the device under actual plant operating conditions.

The first step will be the calibration of the gamma-ray level monitor in the char feed vessel. Since this device is sensitive to gas temperature, pressure and composition, it is important that this step be performed at operating conditions. Once this has been done, the calibration of the flow monitor is obtained by noting the readout indication under conditions of steady char flow in the leg being monitored. The actual flow rate is obtained by measuring the rate at which the level drops in the char vessel. This assumes

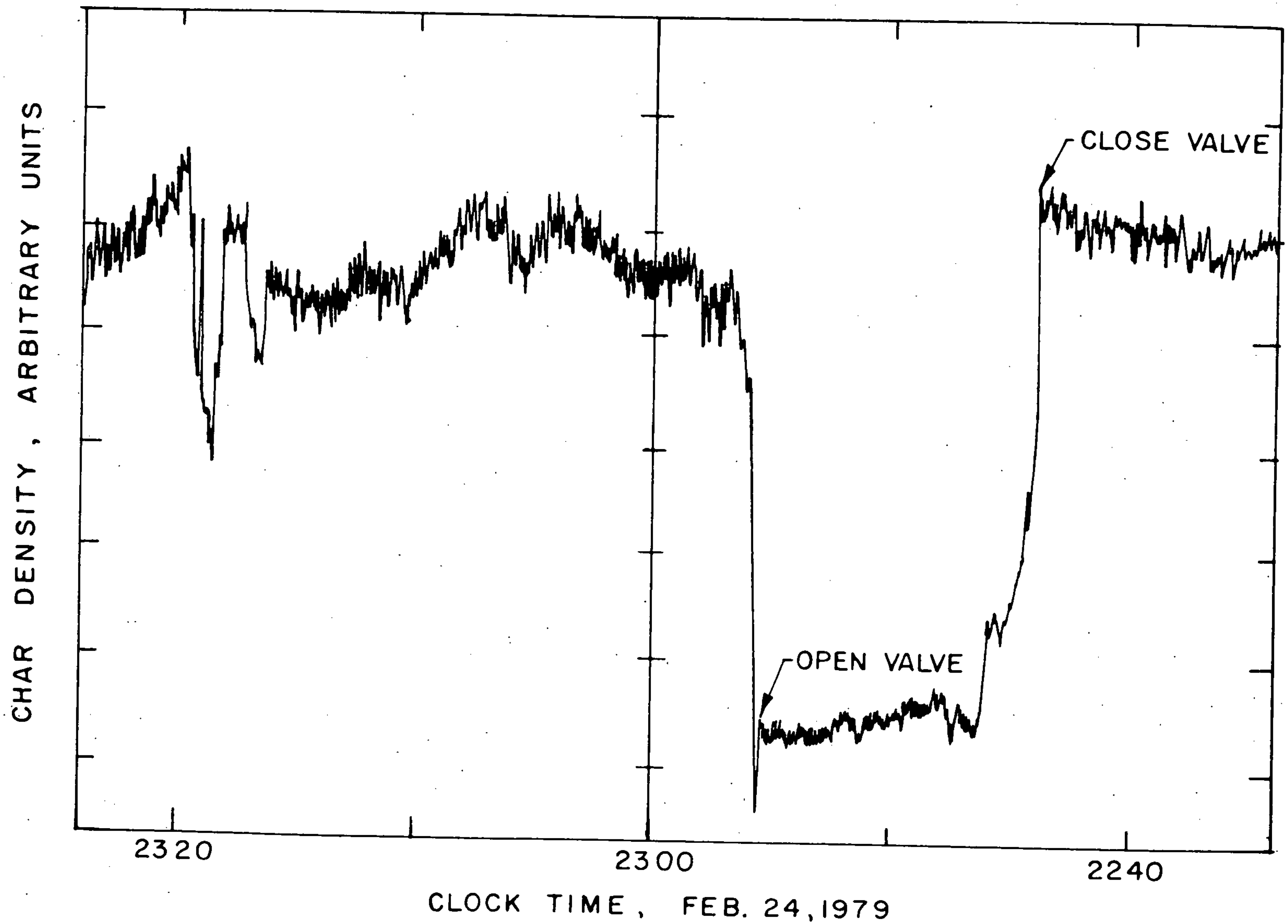

Fig. 9 Recording of Char Density Signal

that char flow into the char vessel has been diverted for the period of the measurement. By repeating the measurement under different flow conditions, a full range calibration will be obtained.

Such a calibration is necessarily dependent on the char velocity during the measurement. If this velocity is essentially constant, then there is a fixed relation between char density, as measured by the flow monitor, and the mass flow rate used in the calibration. But if char velocity tends to vary, then it is important that this velocity be known. For this reason, an acoustic velocimeter may also be necessary in the char lines. This device would use passive cross-correlation[9] of the signals from two microphones to give char velocity. In essence, this technique measures the transit time for flow eddies to travel betwen the microphone locations. Since the separation of the microphones is known, the flow velocity can be directly calculated. When combined with the char density measurement, this gives mass flow rate of the char, even when the velocity is changing. This instrumentation would give the most reliable measure of char flow.

8.0 CONCLUSIONS

The char feed lines at the BI-GAS Pilot Plant represent a situation in which passive acoustic listening is especially well suited for char flow monitoring. The presence in each line of a strong acoustic source (the steam eductor) allows a measurement to be made of the acoustic attenuation caused by the char. A high temperature microphone in the line and a relatively simple signal processor give rapid, sensitive indications of char density.

Although the original goal of providing a flow/no-flow monitor has been achieved, it is now apparent that the same instrument can almost certainly be used as a char density meter. For this, only a calibration is needed, since the device now provides an output signal that varies with char density over a wide range. If the char velocity is also known, the actual char flow rate can be calculated.

Auxiliary features of the flow monitor permit checking its operation and checking the input signal for proper amplitude. In addition, outputs are provided which can be used for making permanent records of the char density or for performing alarm or process control operations. As more operating experience is gained with the flow monitor, the device will likely undergo further changes to make it more reliable, more convenient and more useful in assisting the operation of BI-GAS.

9.0 ACKNOWLEDGEMENTS

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