EFFICIENT ULTRASONIC GRINDING: A NEW TECHNOLOGY FOR MICRON-SIZED COAL

QUARTERLY TECHNICAL PROGRESS REPORT NO. 2
December 16, 1979 - March 15, 1980

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April 3, 1980

Work performed under Contract No. DE-AC02-79ER10466
For U. S. DEPARTMENT OF ENERGY

ENERGY & MINERALS RESEARCH COMPANY
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ABSTRACT

During the second quarter, work focused on establishing a series of experimentally determined parameters for ultrasonic comminution and their translation into the design of an ultrasonic comminution array for Phase I testing. Early work indicated that continuous removal of fines during comminution could significantly increase the production of -10 micron particles. Similarly, varying the mechanical gain of the ultrasonic comminution apparatus and thereby increasing the strain amplitude of the system was shown to enhance fines production. A gain of 3:1 (i.e., a three-fold increase in strain amplitude) produced the best results. These features used with an ultrasonic cylinder segment apparatus resulted in 276% increase in the production of -10 micron fines over that generated by passing coal through a non-activated control.

Thus influenced, the design of the Phase I ultrasonic comminution apparatus will incorporate both a dual-roll and roller/plate capability; it will provide continuous flow of particles through the region of ultrasonic activation, thus permitting removal of fines as they are comminuted; and will function with a gain of 3:1. The Phase I apparatus also offers the flexibility of operating with either traveling or standing ultrasonic waves. Varying the physical configuration (dual-roller or roller plate) and the mode of ultrasonic activation (traveling or standing wave) allows for cost effective testing of four different techniques. Additionally, operating frequency has been reduced to 15 kHz to permit use of off-the-shelf hardware in apparatus assembly and thus expedite testing.

Selection of four representative, well-characterized coals has been completed; after initial testing, 200 lb. quantities of two of the samples will be secured for Phase II experimentation.

Project Description

The objective of this project is to demonstrate on a laboratory scale the technical feasibility and economic promise of efficiently applying ultrasonic energy to the production of -10 micron coal fines. Such a system could overcome the inherent inefficiency and economic penalty of mechanical grinding, while producing better size uniformity in the product. An additional benefit associated with the mechanism of ultrasonic effect is the possibility of selective liberation of ash and pyrite inclusions.

I. INTRODUCTION

Coal processing has become an increasingly important industry as America continues conversion efforts from petroleum to coal. In order to provide coal with combustion performance approximately equivalent to oil or gas, much finer particle sizes will be needed than the conventional plant grind size (75% -200 mesh).

Conventional grinding techniques cannot economically meet this goal. A new comminution technology, ultrasonic grinding, can offer a solution. Because it operates by methods not common to those of conventional grinding systems, it is expected that ultrasonics can significantly enhance grinding efficiency in the -10 micron range needed for various types of processing and "clean coal" applications.

The mechanisms of ultrasonic grinding appear to be:

- Very rapid (10-60 kHz) vibratory promotion of fatigue fracture;
- Promotion of stress corrosion;
- Preferential energy delivery to discontinuities;
- Prevention of small particle shielding by larger ones;
- Cavitation and preferential shear in damp or paste media.

These mechanisms all appear beneficial in producing the desired particle size range by a process entirely amenable to high volume production and at dramatically decreased energy requirements.

II. EXPERIMENTAL PLAN

The program is following the steps outlined below:

Phase I

A. Conduct preliminary ultrasonic comminution tests using existing laboratory equipment.

B. Design and fabricate laboratory-scale ultrasonic comminution apparatus.

C. Using selected samples of candidate coal, conduct experimental runs with and without ultrasonic activation.

D. Evaluate samples produced for particle size distribution and generate Phase II apparatus design data.

Phase II

A. Optimize laboratory comminution equipment.

B. Conduct sufficient experimental runs and evaluation to:

1. estimate maximum requirements of ultrasonic energy to produce ultrafine coal particles;
2. estimate production equipment requirements;
3. demonstrate repeatability of ultrasonic effect;
4. determine if selective fragmentation of coal inclusions occurs.

III. EXPERIMENTAL WORK

During the second quarter, laboratory work was conducted using the two experimental configurations, a compaction mode apparatus (Figure 1) and an ultrasonic cylinder segment apparatus (Figure 2), to determine the effect of vibratory strain and force ratios on ultrasonic comminution and to determine the advantages of continuous removal of fines during comminution.

Increasing the gain of a transducer provides an increase in amplitude of the ultrasonic wave and as a result increases the vibratory strain experienced by the coal being activated. Mechanical gain is normally defined as a ratio between coupler input amplitude and the output amplitude of the vibration delivered to the material being activated. A system with unity gain (1:1) delivers a vibratory motion of the same amplitude as the input; a system with a gain of 3:1 delivers a vibratory amplitude three times the amplitude of the input. Continuous removal of fines as generated prevents their compaction and the attendant dissipation of energy into material already comminuted, and also prevents clogging of the region of the fixture where ultrasonic activation is occurring.

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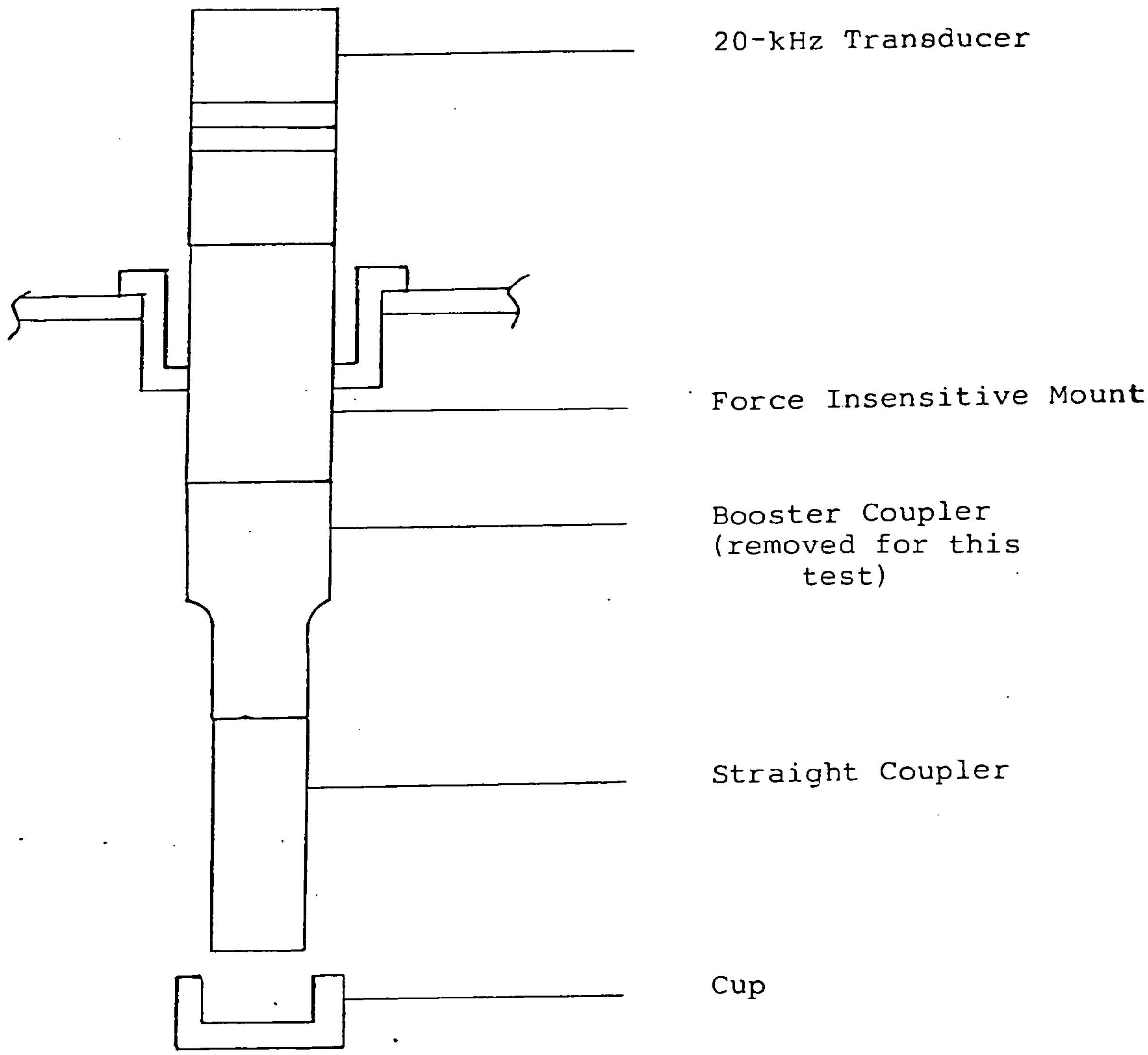


Figure 1

SCHEMATIC OF PRELIMINARY

COMPACTION-MODE COMMINUTION APPARATUS

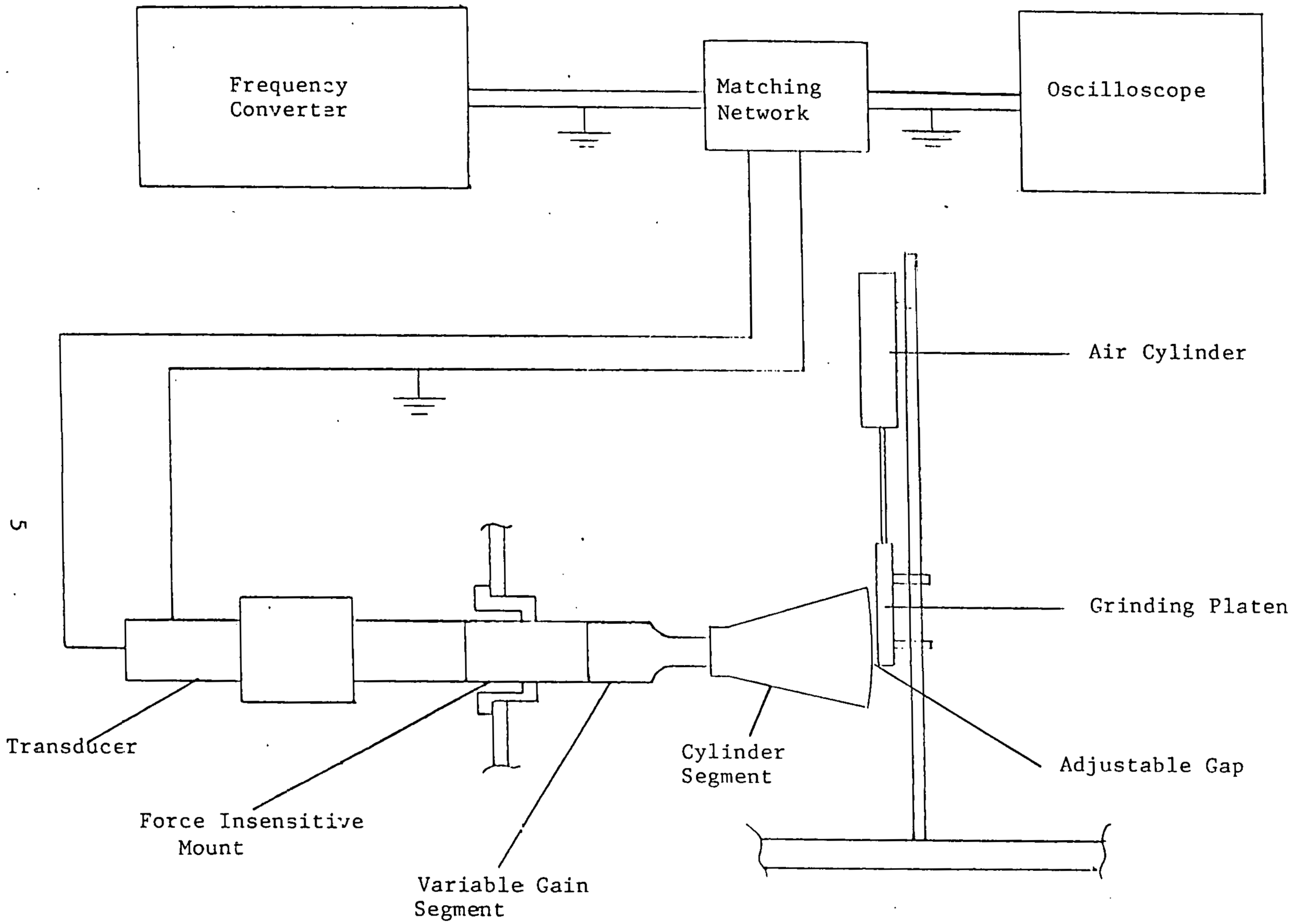


Figure 2

ULTRASONIC CYLINDER SEGMENT COMMINUTION APPARATUS

A. Compaction Mode Apparatus

Early experiments utilized the compaction mode apparatus, which required manual removal of comminuted fines in order to avoid compaction losses in energy. Application of a mechanical booster coupler to the transducer permitted investigation of the effects of different levels of vibratory strain amplitude on coal comminution.

Using a low gain-configuration, samples of 1/8" coal of HGI-93 were subjected to extensive ultrasonic activation. The coal sample was activated for one minute, then screened through a 325 mesh sieve. The +325 mesh fines (44 microns or above) were reactivated first for 30 seconds and screened. The remaining +325 mesh fines were reactivated for an additional 15 seconds and screened. The then remaining +325 mesh fines were reactivated for 10 seconds and screened. Finally, all the -325 mesh fines were ultrasonically activated for one second. This sequence was selected to simulate a situation where generated fines are continuously removed and thus do not compact or hinder continuing comminution.

The ultrasonically comminuted -325 mesh fines were analyzed by sedimentation to determine particle size distribution, with specific emphasis on the -10 micron size range. A marked increase in the quantity of fines in that range has been achieved with the increase in strain amplitude of the ultrasonic compaction mode apparatus driving face. Of the 3.85 grams of 1/8" coal tested, 15 w/o was 10 microns or below after activation, an increase of nearly 100% over the 8.5 w/o 10-micron particles generated in previous tests at lower (1:1) gain. In addition, the advantage of removing fines as generated was reaffirmed.

B. Cylinder Segment Apparatus

Additionally, experiments were begun with the cylinder-segment coal comminution apparatus. This apparatus is intended to provide information for the design of a laboratory scale dual-roller configuration ultrasonic grinder and a roller/plate configuration ultrasonic grinder. A preliminary performance comparison of these two configurations can also be inferred from testing conducted on the cylinder segment apparatus, since it can be modified to simulate the operations of each of the two candidate configurations. Hence, the cylinder segment test apparatus provides a bridge between early compaction mode tests and a laboratory scale ultrasonic comminution apparatus.

During this report period, the cylinder segment test apparatus was set up to simulate a roller-on-plate grinding configuration. Grinding performance versus vibratory strain amplitude was investigated using a mechanical booster coupler attached to the transducer; gains of three and one were investigated.

As the data of Table 1 indicate, the percentage of -325 mesh fines increases with increased vibratory amplitude or mechanical gain. Additionally, Table 2 clearly illustrates nearly 30-fold improvement in percentage of -10 micron fines on an HGI-86 sample compared to previous tests conducted with the compaction apparatus on slightly softer (HGI-93) coal where fines generated could not be removed and tended to inhibit further comminution. The general grinding performance is also improved by the flow-through mode of operation of the cylinder segment apparatus, with marked reduction in +200 mesh fines and increase in -325 mesh fines. The "flow-through" fines removal action of the cylinder segment apparatus was therefore demonstrated to promote increased fines generation. This suggests that the dual-roller or roller/plate grinding configurations, by providing continuous removal of fines generated at the grinding surface, may be expected to produce further improvement in percentage of fines generated.

Table 1

EFFECT OF ULTRASONIC ACTIVATION ON PARTICLE SIZE DISTRIBUTION FOR HGI 86 COAL SAMPLES

Size	Non-Activated Control (w/o)	Ultrasonically Activated With Gain of 1:1 (w/o)	Ultrasonically Activated With Gain of 3:1 (w/o)
+200 mesh	78	66	65
-200+325 mesh	7	11	9
-325 mesh	14	23	26
-50+10 micron	11.4	--	18.8
-10 micron	2.6	--	7.2

Table 2

ULTRASONIC COMMINUTION MODE COMPARISON

Initial Sizing - -6+8 mesh

Size Range	Batch Cup Mode HGI 93 Coal* (w/o of Sample)	Flow-Through Mode HGI 86 Coal (w/o of Sample)
+200 mesh	93.0	65.0
-200+325 mesh	4.0	8.0
-50+30 micron	1.80	5.72
-30+20 micron	0.54	6.34
-20+15 micron	0.20	3.54
-15+10 micron	0.20	3.89
-10 micron	0.26	7.51

Flow-through mode improvement for -10 micron size = $\frac{7.51}{0.26}$ = 28.9:1.

*Data repeated from Quarterly Progress Report No. 1, Table II.

C. Results of Combined High Gain/Continuous Flow Design

Using the cylinder-segment apparatus, 26% of the ultrasonically comminuted coal product was -325 mesh compared to 14% of the coal passed through the non-activated fixture (control sample). The -325 mesh fines of both the control and activated samples were subjected to sedimentation analysis to determine the quantity of -10 micron fines; 27.8% of the -325 mesh fines fell into the -10 micron range for the activated sample compared to 18.8% for the control. As Table 1 indicates, this translates to a total -10 micron production of 7.23% for the ultrasonically comminuted sample versus 2.63% for the control, which represents an increase attributable to ultrasonic activation of 276% in the -10 micron range.

IV. LABORATORY SCALE APPARATUS DESIGN AND PRIMARY COAL SAMPLE SELECTION

A. Experimental Apparatus Design

On the basis of the successful experimental results of increasing gain and providing continuous removal of fines during testing, design is in process on the Phase I dual-roller and roller on flat plate laboratory scale comminution testers. The dual-roller apparatus (Figure 3) will consist of one activated and one non-activated roller. The activated roller will be composed of two transducers, two force-insensitive mounts and two sets of slip-rings. The design will include a differential roller-speed adjustment to permit introducing controlled slippage and attrition, which may be beneficial. The two-transducer system permits the establishment of traveling waves as well as standing waves on the roller, in order to compare the benefits of each mode. If the second or receiving transducer is connected to a resistive load and properly adjusted for maximum power absorption, then minimum energy will be reflected back into the driving transducer (Figure 4A). When there is no reflected energy, the transmitted ultrasonic wave travels down the entire roller length; since a majority of the energy is absorbed into

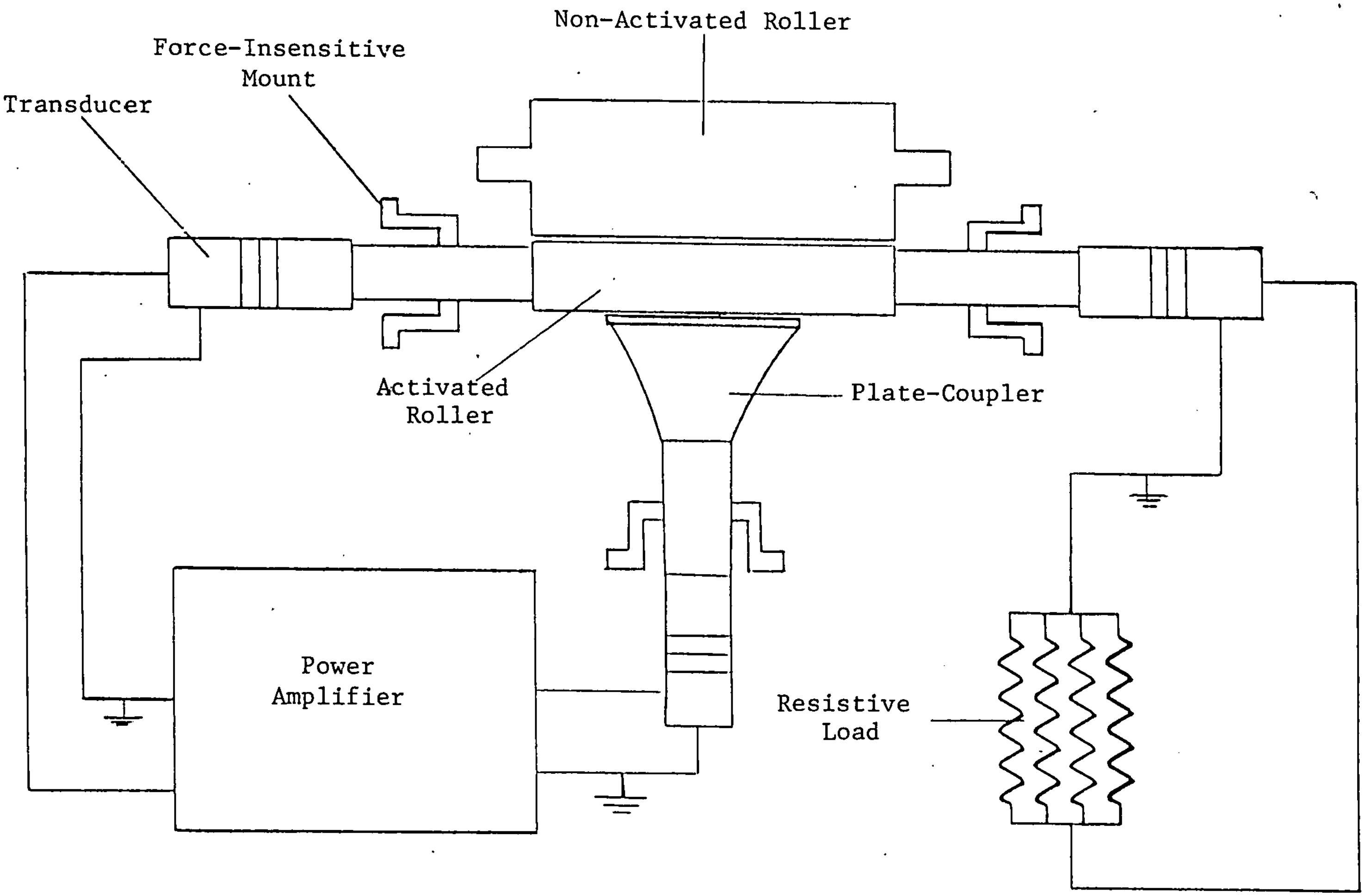
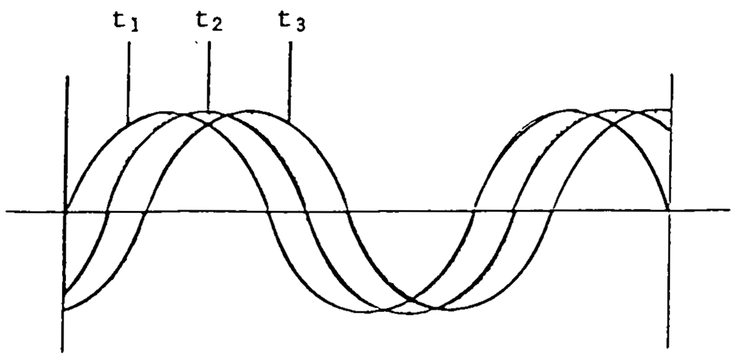
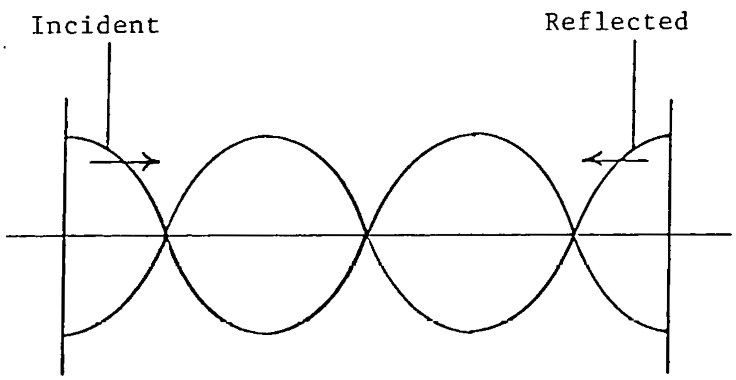


Figure 3

PHASE I - ULTRASONIC ROLLER APPARATUS



(a) Traveling Waves



(b) Standing Waves

Figure 4

TRAVELING AND STANDING WAVES

the coal being ground or into the receiving transducer, no nodes or antinodes are established in the roller. Conversely, if the receiving transducer is disconnected from a dummy load, then some energy is reflected and standing waves are established on the roller with defined nodes and antinodes (Figure 4B). While the standing wave mode requires less mechanical complexity and could use somewhat less power, the traveling wave mode could, by avoiding vibrational nodes, provide somewhat more uniform grinding and slightly higher power delivery to the coal being ground. The relative effectiveness and benefits of traveling and standing wave modes on coal comminution will be examined using the dual roller apparatus being designed.

In the envisioned apparatus, the activated roller will be 6.6" long and 2.75" in diameter. This design differs from the original configuration (Figure 5) described in Technical Progress Report No. 5 in two ways. First, the entire system length has been shortened to reduce flexing of the rotating members. Second, the frequency of operation has been changed from 20 kHz to 15 kHz to permit the use of off-the-shelf transducers to expedite program testing. The lower frequency is additionally expected to increase the ultrasonic effect and facilitate scale-up because of equipment design simplifications.

The roller-on-plate apparatus is being designed concurrently. For economy, some hardware is common to both units. In this latter unit the plate will contact the activated roller. It will be connected to a coupler, force-insensitive mount and 15-kHz transducer, as will the activated roller. Therefore, either the roller or the plate may be activated allowing investigation of roller-plate operation from the point of view of activated roller or activated plate.

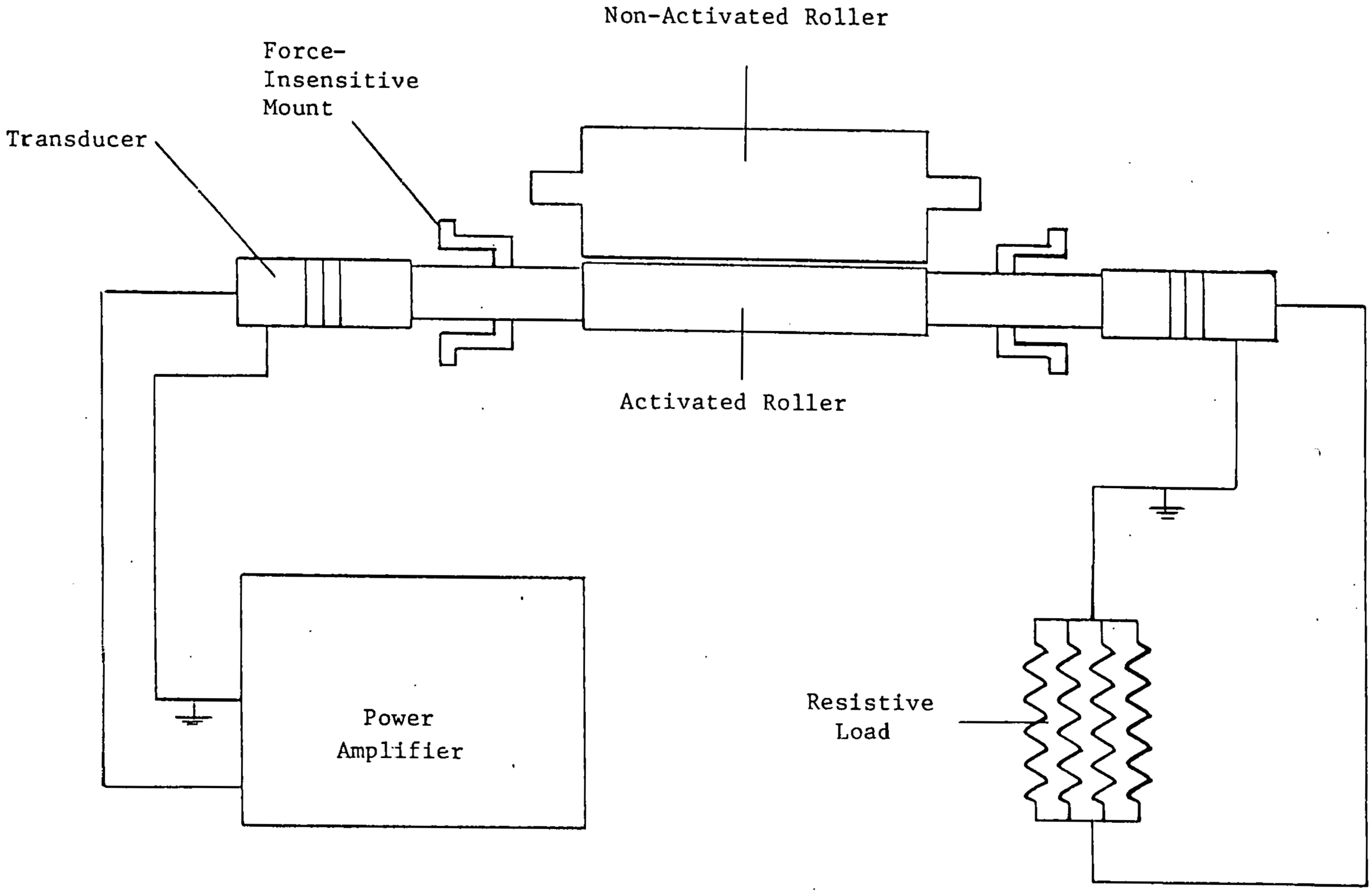


Figure 5

PRELIMINARY ULTRASONIC ROLLER APPARATUS DESIGN

B. Coal Sample Selection

Four representative, well-characterized coals available in sufficient quantity have been selected:

1. Lower Philpott (PSOC-769)

HGI - 108.6
Ash Content - 5.39% (dry)
Sulfur Content - 0.93% (dry)
Rank - Low Volatile Bituminous
Location - Clarkesville, Arkansas;

2. Elk Lick (PSOC-688)

HGI - 97.5
Ash Content - 18.55% (dry)
Sulfur Content - 2.72% (dry)
Rank - Low Volatile Bituminous
Location - Mt. Storm, West Virginia;

3. Middle Kittanning - Pennsylvania C (PSOC-330)

HGI - 56.7
Ash Content - 6.11% (dry)
Sulfur Content - 2.77% (dry)
Rank - High Volatile B Bituminous
Location - Hillsville, Pennsylvania;

4. Ohio #6A - Lower Freeport (PSOC-275)

HGI - 56.7

Ash Content - 6.61% (dry)

Sulfur Content - 2.14% (dry)

Rank - High Volatile A Bituminous

Location - Cadiz, Ohio.

Two of these four coals will be chosen and approximately two hundred pounds of each will be obtained.

V. FUTURE WORK

Conduct further tests with cylinder-segment apparatus.

Complete fabrication and assembly of roller equipment.

Conduct tests on roller apparatus and generate data for optimization of equipment.

Optimize final apparatus and prepare for Phase II experimental runs.