Section 13.0: Plasma Jet Oscillation

Experiments using acoustic analysis equipment and a high-speed digital camera were conducted to measure the plasma jet oscillation rate of the Virginia Tech Plasma Torch. Acoustic tests were performed with methane and argon. The acoustic equipment was also used to measure the background frequencies of the lab while the torch was shut down, while all other equipment was running, to ensure that the acoustic data collected was of the torch and not some form of background noise. The digital camera was used to observe the plasma jet while the torch operated on methane, argon and mixtures of the two.

Plasma jet oscillation can be controlled by changing the power input frequency and voltage. For a given feedstock flowrate, the frequency of the input power controls the rate of plasma jet oscillation, while the voltage determines the plasma jet length. Most common welding power sources are designed to operate on either single-phase (AC) or three-phase power. Devices that convert the input power to DC use rectification and filtering to produce a DC output. However, most welding supplies are unfiltered and the level of the DC voltage varies. These voltage oscillations cause changes in the arc dynamics which in turn change the shape and size of the plasma jet. Typically, lower voltages produce smaller jets while higher voltages produce larger jets. Arcs confined to constant current carry more potential energy per unit width at higher voltages. Therefore, a gas passing through a high voltage arc will absorb more energy and reach a higher temperature, thus increasing the rate of dissociation. Control of the shape and size of the plasma jet at a certain frequency would be ideal in applications which require pulsing plasma torches which never extinguish (unlike pulsed plasma torches which ignite and blow off).

13.1: Test Procedure

Acoustic tests were conducted using a high-sensitivity B&K microphone attached to an amplifier and National Instruments data acquisition system. All tests were run at a current level of 27% (≈35 Amps) and a feedstock flowrate of 20 SLPM. All test conditions were kept constant except the type of feedstock. Two tests were run with methane and two with argon. These tests were designed to observe how feedstock type affected plasma jet oscillation, and also to see if the oscillation rate changed from test to test using the same feedstock. Acoustic data was recorded into a LabVIEW data acquisition program. Harmonic frequencies were averaged over a period of approximately 20 seconds to clarify the harmonic peaks. A fifth test was conducted with the welders running at 27% and the torch operating with 20 SLPM of methane. However, the torch was purposely not ignited. This test was used as a background check to ensure that the data collected in the previous tests was not the hum of the welders, sound of the feedstock passing through the torch, or some other background noise.

In addition to acoustic testing, high-speed digital photos were taken of the plasma jet at a rate of 1000 frames/sec using an EG&G Reticon Digital Camera. The camera was capable of taking between 30 and 1000 frames/sec and could store up to 2048 frames. A zoom lens was used to get a more detailed view of the plasma jet. The test conditions are shown in Table 13.1.

Table 13.1: Optical Examination Test Conditions

Test Run	**Frame Rate (frames/sec)**	**Feedstock**
#1	500	25 SLPM (Methane)
#2	1000	25 SLPM (Methane)
#3	1000	15 SLPM (Methane)
#4	1000	10 SLPM (Methane)
#5	1000	20 SLPM (Argon)
#6	1000	10 SLPM (Argon) 15 SLPM (Methane)
#7	1000	15 SLPM (Methane)

To begin the test, the camera would be started a few tenths of a second before the plasma torch was ignited. Upon analysis of the pictures, the plasma jet was found to oscillate, forming large and small jets at a fixed frequency. By recording these oscillations at a known frame rate it was possible to determine the frequency at which the plasma jet oscillated.

13.2: Results and Discussion

To verify that the plasma jet oscillation was indeed caused by the output characteristics of the power supplies, a waveform of the output voltage was collected. This waveform is shown in Fig. 13.1. The power supplies were DC arc welders, operating from a three-phase AC source. For three-phase power supplies, the variations of the rectified, DC waveform complete a full cycle with a frequency 180 Hz. It is clear from the figure that the time interval between the first and last troughs of each cycle is approximately 5.5 ms, which corresponds to a frequency of 180 Hz, but there is also a 360 Hz signal present. Further investigation is needed to determine why the plasma jet was observed to oscillate at 180 Hz rather than 360 Hz. However, once the characteristics of the power supply were known, they were compared with the results of the acoustic and digital camera tests to see if any correlations could be made.

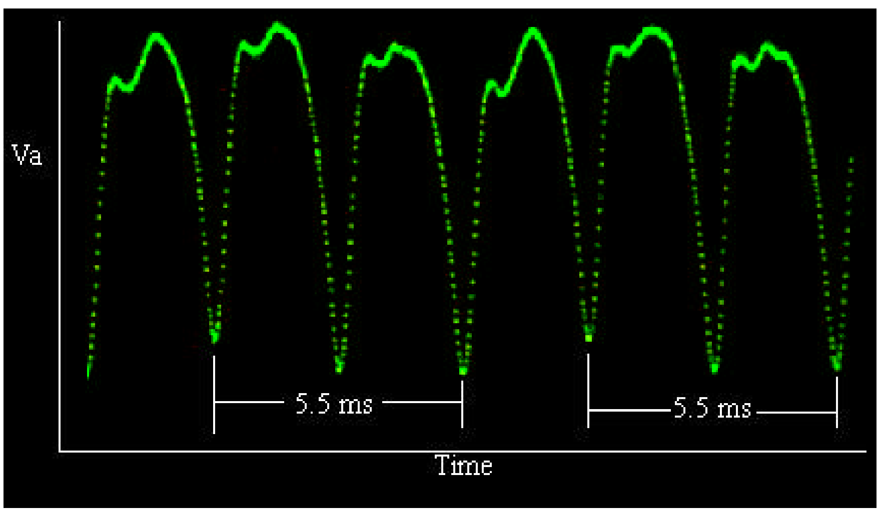

Figure 13.1: Voltage Waveform of Torch Power Supply

13.2.1: Acoustic Test Results

The results of the acoustic testing are shown in Figs. 13.2(a) and 13.2(b). These graphs clearly showed a defined peak at 180 Hz for both methane and argon. The background noise check did not exhibit this peak so it can be concluded that the 180 Hz signal emanated only from the torch. Harmonics of 180 Hz were also present. All four runs (two methane and two argon runs) had the same acoustic peak at 180 Hz. This indicates that the arc rotation rate was not picked up by the acoustic instruments as being the 180 Hz signal, since it is a function of feedstock type and flowrate. Notice that the methane runs had larger relative signal amplitudes than the argon runs. This simply means that when the torch operates with methane it is louder. This was confirmed by listening to the torch as it operated with both argon and methane.

Acoustic Testing Results

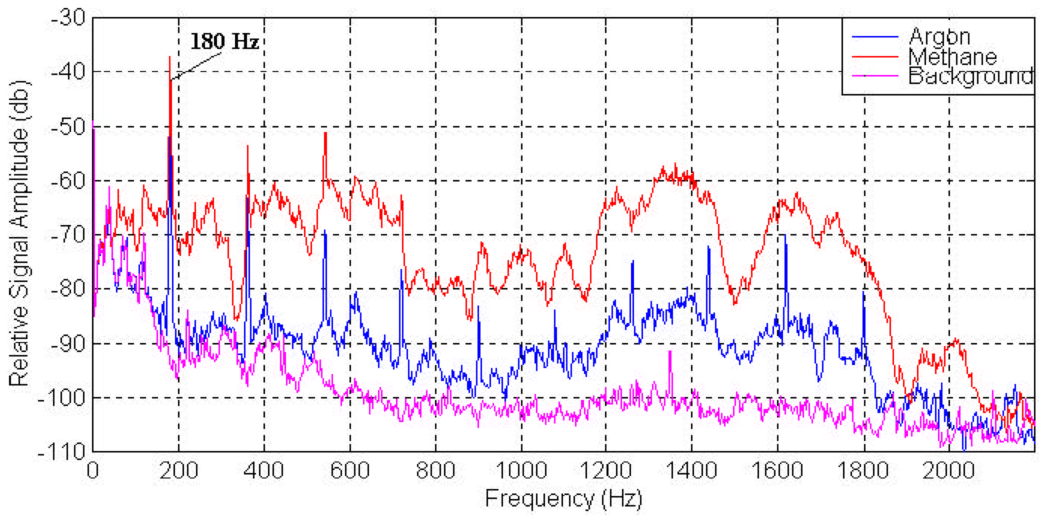

Figure 13.2(a)

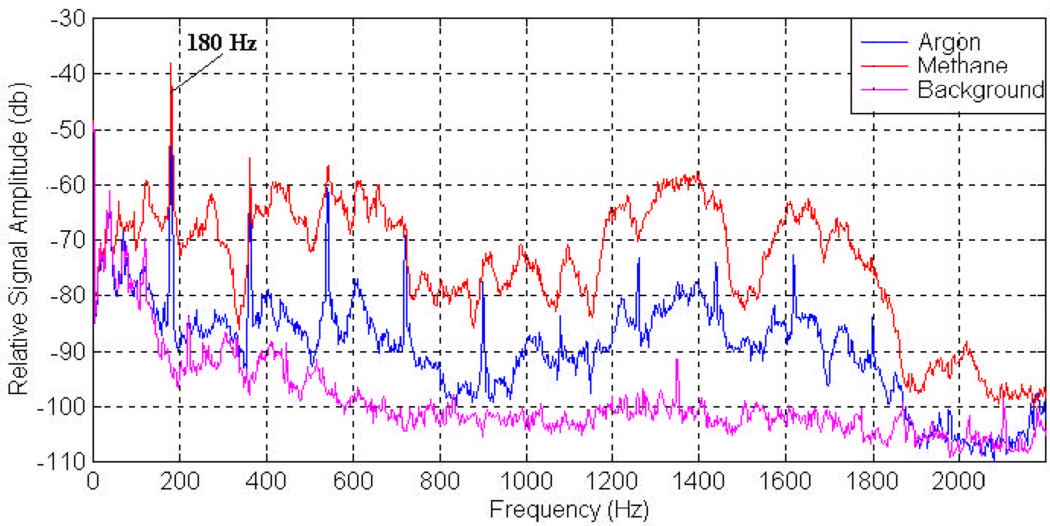

Figure 13.2(b)

13.2.2: Optical Test Results

The acoustic testing provided strong evidence of plasma jet oscillation at 180 Hz, but not proof. However, the digital photos taken with the high-speed digital camera confirm that the jet length is oscillating at approximately 180-185 Hz. Twelve photos taken during run #6 are shown in Fig. 13.3.

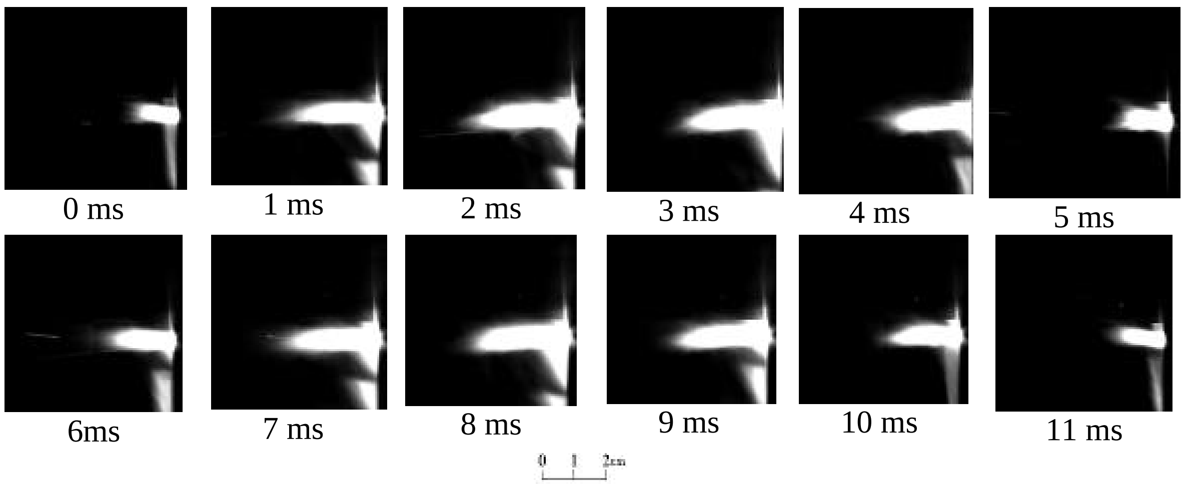

Figure 13.3: Digital Photos of Plasma Jet Oscillation

The photos shown in Fig. 13.3 are from run #6 (10 SLPM argon, 15 SLPM Methane), although all the test runs demonstrated this type of jet oscillation at the same frequency. In Fig. 13.3, the jet oscillates between a small and large jet twice, completing the two cycles in 11 ms.

$$\frac{2cycles}{11ms} \approx 182Hz$$

The plasma jet oscillation recorded in the acoustic tests and digital camera analysis were definitely caused by the characteristics of the power supply outputs and not due to some aerodynamic effect such as arc rotation. Arc rotation is induced by flow swirl and dependent on flowrate and feedstock density and viscosity. The seven tests used to collect digital camera data had several different flowrates, two types of feedstocks and one test with a mixture of feedstocks. Under all circumstances the plasma jet oscillation rate remained constant, proving that arc rotation could not have been the cause of the oscillation.

13.3: Recommendations and Final Remarks

Acoustic tests of the plasma torch in operation and digital camera analysis of the plasma jet confirmed that the plasma jet length oscillated at a frequency of approximately 180 Hz, caused by the output of the three-phase power supplies used to power the torch. The most striking conclusion from these tests is that plasma jets can be controlled and made to oscillate at a given frequency by controlling the input voltage waveform. Applications that require a pulsing plasma torch to produce jet fluctuations at a given frequency, but never extinguish, would be ideal for this type of device.