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Research Article

Nanosecond Pulse Stimulation in the Ni–H_2 System

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Abstract

Brillouin Energy and SRI International (SRI) have been performing calorimetry measurements on the Ni(Pd–Ni/ceramic/Cu(Ni) coated tubes in a H_2 atmosphere with nanosecond pulses applied across the ceramic coating. We have been testing new materials, material fabrication techniques, and electrical stimulation methods to produce power and energy output in excess of that reported earlier. By applying fast pulses of several hundred volts and tens of nanoseconds long, the current follows the "skin-effect" principle and is concentrated at the Ni–ceramic interface but returns through the bulk of the Cu. Two stimulation methods were used – steady-state and dynamic. In the steady-state method, the pulse power is measured directly using fast oscilloscopes that record the voltage across the tube and a shunt resistor in series with the tube. The resistance of the shunt resistor is measured accurately under DC and pulse conditions. The input pulse power is determined by multiplying the calculated root-mean-square voltage and current and recorded every 10 s. Using a sophisticated model of the calorimeter with up to 15 coefficients, the power reaching the five temperature sensors is determined during simultaneous continuous ramps of both heater and pulse powers. The power emanating from the tube is determined during sequences of more frequent low voltage pulses (LVP) and compared to that found using less frequent high voltage pulses (HVP). The power determined during the more frequent LVP is set as the input power during that sequence. The power of the stimulation pulses during the less frequent HVP sequences is maintained equal to that during the more frequent LVP. Then the power calculated from the tube is divided by that calculated during the reference sequences, giving a so-called coefficient of performance (COP). We have shown an increase in both absolute LENR power produced and in COP.

Keywords: Calorimetry, Excess energy, Hydrogen gas, Nickel, Pulse stimulation

1. Introduction

For over five years, SRI International (SRI) has been performing tests on two different versions of Brillouin Energy Corp.'s low-energy nuclear reactors (LENR) [1]. We have operated these reactors independently in an attempt to

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verify results that Brillouin has found with these reactors and others like them. We have also monitored and advised Brillouin on the results from reactors operated by Brillouin in their own laboratory. This report updates the results [2] obtained by studies in SRI's laboratory, as well as verification and validation of results obtained in Brillouin's laboratory over the past two years. Brillouin has indicated that it has designed the control systems in its reactors to drive the underlying physics of LENR, as described in its Controlled Electron Capture Reaction (CECR) hypothesis [3]. The CECR hypothesis explains how scientists at Brillouin believe their reactors generate controlled LENR reaction heat. Our study did not attempt to prove or disprove Brillouin's CECR hypothesis.

The systems tested and described in this report consist of three parts: tubes; reactors; and calorimeters. The tubes are the reactive components of the system. The reactors provide the environment and stimulation that causes the tubes to produce reaction heat. The calorimeter is used to measure the thermal efficiency and absolute heat produced by the tube-reactor system. The calorimeter was designed by both SRI and Brillouin personnel to be perfectly matched to the reactor. The results from four of these reactors are described in this report.

Brillouin's system design utilizes compensation calorimetry, in which the tube and reference temperatures are held constant by varying the input heater power while applying different types of stimulation that also input power to the reactor/calorimeter. Recently Brillouin Energy started using a thermal model based on heat input and loss identification developed by an independent commercial third party. This "dynamic" method of analysis allows us to analyze all power entering or affecting the tube as well as all power emanating from the tube based on differential equations describing temperatures and power measurements. While this requires 100 h of calibration and up to 40 h of excitation to verify a calibration, it allows testing of 12-parameter variations per hour versus one or two in the traditional steady-state method.

2. Experiment

2.1. Design

The tubes consist of a metal or ceramic substrate, which in some configurations includes a heater and thermocouple with several spray-coated layers. Generally, these coatings alternate between a hydrogen-absorbing metal and an insulating ceramic. One example is shown in Fig. 1. Other designs have used more or fewer layers. All of the layers are porous, allowing the gas(es) in the reactor chamber access to all coatings. A heater, if present, and a thermocouple are located in the center of the tube. The power to the heater is measured directly from the voltage and current supplied by the direct current (DC) power supply. A photograph, schematic, and description of the reactor/calorimeter system can be found in our earlier report [2].

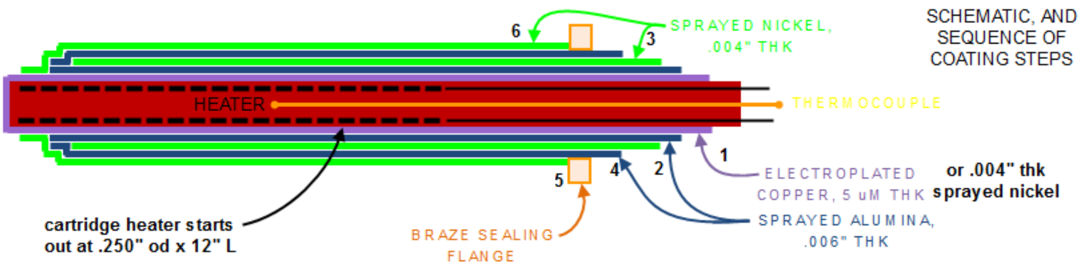

Figure 1. Example of Brillouin's recent hydrogen hot tubes.

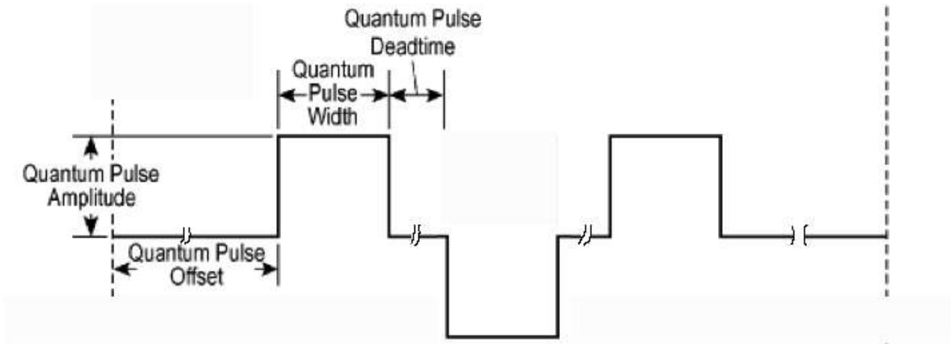

Figure 2. Example of Brillouin's "Q-Pulse".

2.2. Measurement

The outer active layer is stimulated by sending pulses through the outer layer or layers and returning electrically through the innermost layer. The nature of the pulses is such that its current travels primarily on the surface of the metal in contact with the ceramic (the "skin effect"). This effect is caused by the very fast rise time of the pulses. An example of this pulse design, which Brillouin refers to as a "Q-Pulse", is shown in Fig. 2. The pulse width is presently used is from ~30–10,000 ns with a duty cycle normally of less than 1%. More detail on the pulse trains are shown here [3].

The stimulation power imparted to the tube is measured using a circuit shown in Fig. 3. The pulse is generated by a proprietary Q-Pulse board and delivered to the tube using series and termination resistors that help match the load impedance to that of the pulse board output. Using a high-speed oscilloscope, the voltage across the end of the tube nearest the pulse board (V_1) is measured as well as the voltage across the opposite end of the tube (V_2) across the termination resistor (Z_{term}). The Z_{term} also acts as a current measuring resistor so the current is calculated as

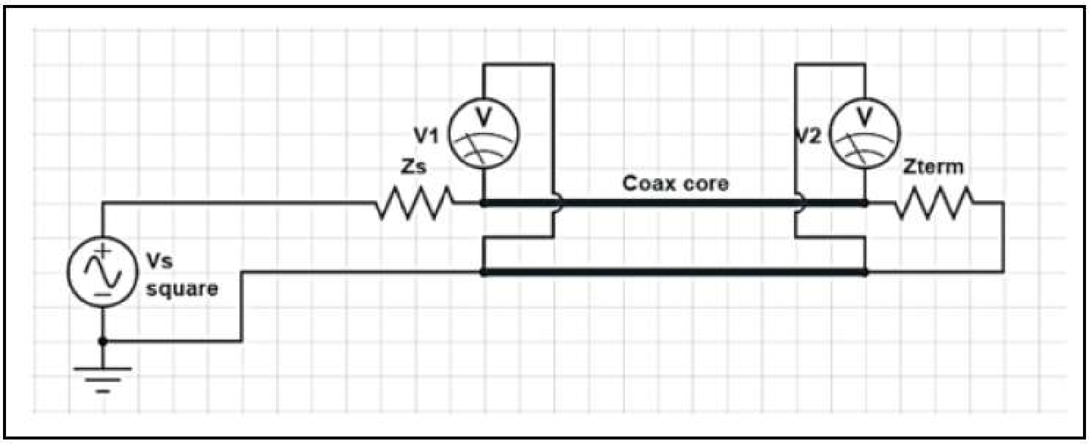

Figure 3. Pulse power measurement circuit.

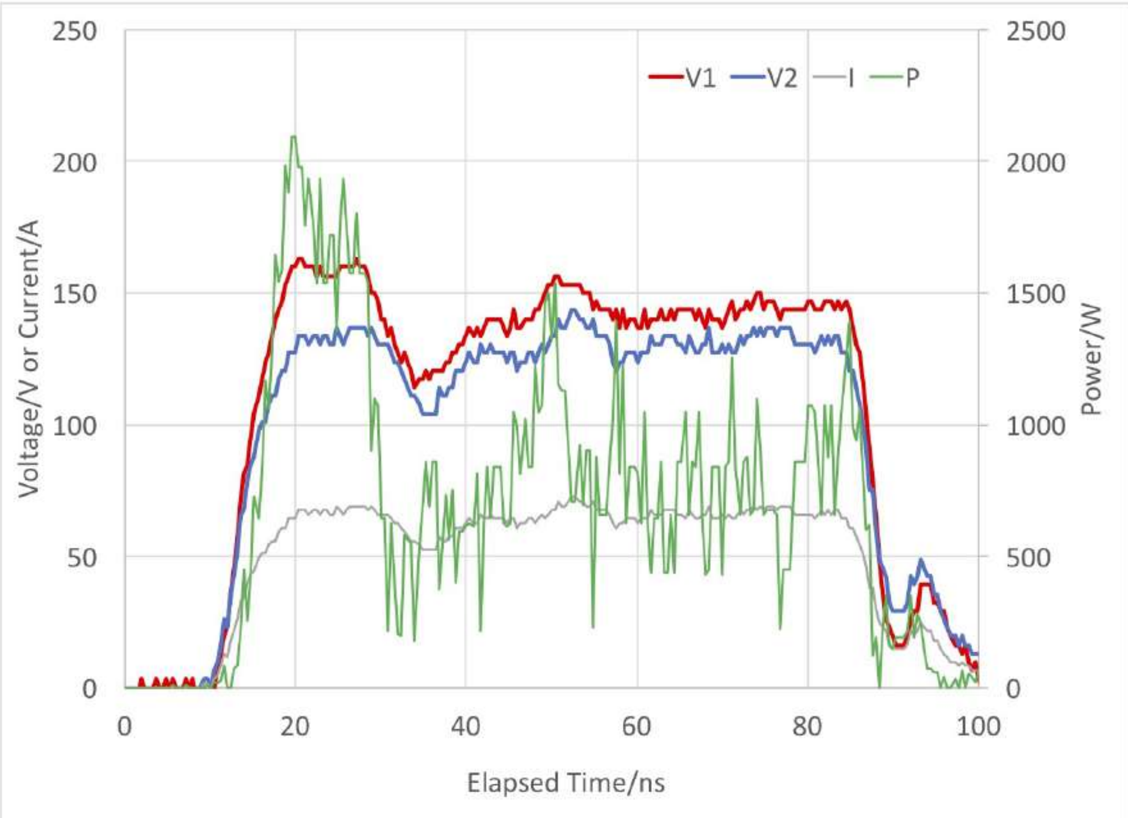

Figure 4. Measurement of the Q-pulse power across the tube.

V_2/Z_{term}. The root mean square (rms) voltage across the Z_{term} is then converted to the rms current.

The power imparted to the tube is determined using the red and blue voltage traces shown in Fig. 4. The difference between the two voltage traces is calculated after aligning them in a way that minimizes the time difference. This overestimates the power imparted to the tube by a small amount since any phase lag between voltage and current would impart less input power. The current calculated from V_2 is shown in black and the product of it with the voltage difference (power) is shown in green. It has been shown that the power calculation is essentially the same (within measurement error) whether it is calculated by multiplying the current and voltage plots point by point or by multiplying the calculated rms voltage by the rms current. This calculated power is referred to as Core Q Power.

In compensation calorimetry the heater power is varied to keep either the tube or inner block at constant temperature, which generally also keeps the other at a constant, but slightly different, temperature. The difference between the heater power with and without stimulation determines the effect of the stimulation. If this difference is greater than the stimulation that reaches the tube, then energy is being produced in the tube. Approximately 50 different parameters are collected allowing for calculation of Reaction Power (the power produced by the process induced by the pulse stimulation). Several calculation methods are possible from these parameters. In addition, two different stimulation sequences are used. In the Analysis section we describe these two sequences and the calorimetry method used for each of them.

2.3. Operation

A description of the data acquisition system with a copy of the graphical interface has been described earlier [2]. The program has several panes allowing for control of temperature, pressure, pulse voltage, pulse power, pulse width, and pulse repetition rate and gas composition. The program also collects the heater power, the pulse power at the generator (as well as at the tube), all temperatures, water flow rates, and gas pressure. The concentration of hydrogen and oxygen in the argon blanket are collected and measured. In all, 50 different parameters are collected and stored every 10 s. A sequence file can be used to automatically change any or all of the input parameters at specified intervals over a multi-day or multi-week period.

The sheath containing the tube is operated with a static fill of hydrogen, and occasionally helium or argon, gas held at constant pressure up to 15 bar. The temperature of the tube is held constant using its embedded heater and thermocouple and controlled from 200 to 600°C. The outer block temperature is held at 25°C using water flow from a Neslab® recirculating constant-temperature chiller.

The power emanating from the Q-pulse generator board, or that applied directly to the tube, is held constant as chosen by the program's front panel or the sequence file. Generally, the pulse amplitude (voltage) and pulse width are chosen. The repetition rate is adjusted automatically to maintain the chosen pulse power. Only a minor fraction of this power from the generator board reaches the tube as most of it is lost as heat in the termination resistor. This is necessary to get an accurate measure of energy actually dissipated in the tube and to match the load impedance to that of the generator thus preventing reflections that could cause measurement errors. Of that reduced power only a portion of it influences the heater power as explained in the "Measurement" subsection above. The actual pulse power is measured directly via the methodology presented above.

During this project several stimulation methods were tried to find one that can act as a blank (no excess power) using similar Core Q-Power. The DC resistive heating of the tube surface coat, was used occasionally and required changing electrical connections and using measurement hardware different from that used for the real-time Core Q-Power calculation. Ideally these methods need to be compatible with the data collection's software's calculation designed for the low duty cycle Q-pulse square waves and not require hardware changes. Some of the methods tried were: (1) straight sine waves, (2) low duty cycle square waves, and (3) large pulse widths with long rise times. Ultimately, calibration runs used Q-pulse parameters that were known not to produce LENR heat low voltage pulses (LVPs) but impart the same power to the tube as parameters expected to show LENR heat, i.e. high voltage pulses (HVPs). The hardware was modified to allow pulsing at much higher repetition rates.

Operating in power compensation mode, the computer keeps the inner tube, or outer heat spreader, temperature constant at its set point. When power is imparted from the Q-pulse, the heater power is reduced to compensate and maintain a constant temperature. Hence, the tube temperature and the inner and outer block temperatures are all held constant when using the same tube gas.

Operating at constant gas pressure, a sequence was operated from 200 to 600°C in 50°C intervals. At each temperature a given DC power was applied to the coating on the tube. This process was then repeated but applying constant power pulses varying pulse width at each temperature.

Two major methods of operation were employed, each requiring a different analysis method. The first method operated with the reactor at a steady-state temperature and input powers, which we refer to as the steady-state stimulation (SSS) method. In our second approach, the dynamic stimulation (DS) method, the heater power was ramped smoothly through a maximum and back down while smoothly ramping Q-power up and down several times. The DS method was developed to allow for many Q-pulse parameters to be tested in less time. On occasion we would interrupt the DS to allow the system to achieve a steady-state for several hours.

The SSS method was operated in power compensation mode, where the computer kept the temperature constant at either the tube or the inner block. When power was imparted from the Q-pulse, the heater power was reduced to compensate and maintain a constant temperature. Hence, when the inner and outer block temperatures are held constant, the tube temperature will respond to the stimulation. The output power (calculated from the inner minus outer block temperatures) did not change as the input power compensates for the total power emanating from the tube. The total tube power included the stimulation power and the power due to reaction heat (i.e. LENR power).

2.4. Analysis

The earlier report [2] describes two different analysis methods employed in the effort. Here we describe the stimulation and analysis methods employed most recently.

2.4.1. *SSS method*

In this method, the absolute heater power necessary to maintain constant temperature without Q-pulses present is not part of the output power calculation. We realize that only a fraction of the heater power may be imparted to the tube because the heater/thermocouple combination has measurable losses to the rest of the calorimeter and to the environment. Instead the temperature controller is instructed to keep the inner block at a constant temperature while low voltage calibration pulses are imparted to the tube and measuring the heater's response at different temperatures. The difference between the heater power with and without the LVPs voltage pulses (LVP) is called P_{drop}. At each temperature, a linear function ($P_{\mathrm{drop}} = mP_{\mathrm{LVP}} + b$) is determined. The b offset parameter is always insignificant and is not used in the analysis.

P_{drop}, also called heater power compensation (HPC), is determined for different amounts of LVP calibration power. This method is analogous to the traditional isoperibolic calorimeter analysis except that it substitutes heater power compensation for the temperature difference. In order to calculate Q_{reaction} as output power minus input power, we compare the heater power compensation (HPC) from LVP calibration to that from HVP stimulation. Using this LVP calibration the relationship between input power and HPC is determined so that with input pulse power the HPC can be used to back calculate the power from the pulses imparted into the tube. Q_{LVP} and Q_{HVP} are the actual Q-pulse powers measured when low voltage and high voltage HVPs are applied, respectively.

First, the linear relationship between HPC and Q_{LVP} is found by fitting a linear equation to HPC vs Q_{LVP} when Q_{LVP} is varied across the same range of powers as Q_{HVP}. These linear coefficients are then applied to the measured Q_{HVP} to calculate HPC (LVP), the amount of HPC measured at the same temperature and pulse power at low voltage, where no reaction heat is expected. Q_{reaction} is then calculated as shown in Eq. (1), where HPC (HVP) is the actual HPC measured when the HVP is applied. Equation (2) is then used to calculate COP. An alternate calculation is shown in Eq. (3). In the latter equation, the COP is calculated as the ratio of the HPC over the Q-pulse power at high and low voltage.

$$Q_{\mathrm{reaction}} = \mathrm{HPC(HVP)} - \mathrm{HPC(LVP)}, \tag{1}$$

$$\mathrm{COP} = Q_{\mathrm{reaction}}/Q_{(\mathrm{LVP})} = (\mathrm{HPC(HVP)} - \mathrm{HPC\ (LVP)})/Q_{\mathrm{LVP}}, \tag{2}$$

$$\mathrm{COP} = (\mathrm{HPC(HVP)})/Q_{(\mathrm{HVP})}/(\mathrm{HPC(LVP)})/Q_{\mathrm{LVP}}. \tag{3}$$

2.4.2. *DS method*

The DS method employs a model with several components, each representing individual components of the calorimeter. Linkages between these components (and from a component to the reference room temperature) are either conductive or storage. Temperatures are measured between the heat spreader and the tube sheath (inner block) and on the outside of the cylindrical heat spreader (outer block). One differential equation (in time) models the heat imparted to the tube using a function of the difference of the tube and outer block temperature, a function of the tube and inner block temperatures, and divided by the function of the ability of the tube to store heat. Each of these three components have a coefficient that is determined fitting the temperature data to the actual power measured using LVPs as described above. A second equation does the same for the inner block. The model then yields a simple equation for power equal to a coefficient time the difference between the tube and inner block temperatures.

These functions are simple 3-coefficient binomial equations, yielding 15 possible parameters. These parameters are then used to calculate the amount of heat emanating from the tube during an attempt to produce LENR heat. A comparison between the calculated power emanating from the tube during an active run and that from the calibration run at the same temperature and with the same Core Q Power is used to determine the amount, if any, LENR heat was produced. When the DS runs were interrupted to achieve a steady-state, the amount of heater power determined to affect the tube was subtracted from both the input and output powers before calculating COP. The computer application MatLab® is used to determine the best fit parameters.

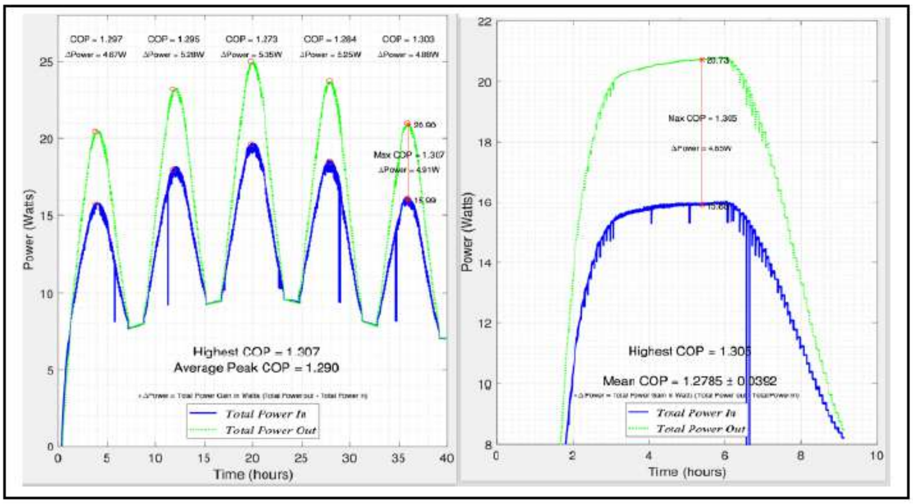

Figure 5. (a) Instantaneous COP during DS run and (b) COP during 4 h at maximum stimulation.

b]

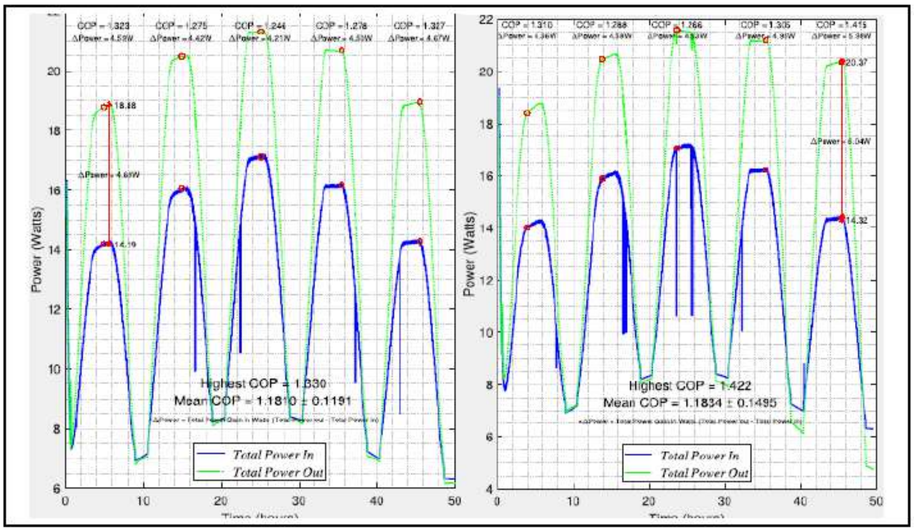

Figure 6. COP during two different DS runs with 2 h at maximum stimulation.

3. Results and Discussion

A tabulation of all experiments run to date in the IPB calorimeters is available on the Brillouin Energy web site [4]. Only a fraction of the total number of experiments will be covered in detail. The runs detailed in this analysis of SSS runs generally used a 100 ns pulse width with similar Q-power on the tube at different voltages. We attempted to keep the CoreQPow relatively constant at each temperature.

Table 1 summarizes the COP results from recent SSS runs. Using the COP as defined in Eq. (3), this shows the COP to be much greater at 250°C (1.27) than at 400°C (1.00). The power compensation/CoreQPow is very dependent on the pulse voltage at 250°C but is essentially unchanged at 400°C. Although the total pulse power from the generator is constant, the pulse power measured at the tube does vary with pulse voltage, even though we attempted to keep Core Q-Power constant by also varying the repetition rate and/or pulse width. Still, the magnitude of the power compensation is a greater percentage of the pulse power at 350 V than at 35 V. Calculations show that Q_{reaction} is greater at 350 V than at 35 V (e.g. 5.3 W versus 3.5 W in one run).

The DS method employed recently calculated two different COP results. The first was the average COP over the complete stimulation run. The other result calculated instantaneous COP, especially at the point of greatest stimulation amplitude. Two tubes showed particularly good COP's both in the average and instantaneous calculations. In general, the highest COP's were obtained using pulses of amplitude 325–350 V and $\leq$100 ns pulse width with <1% duty cycle. Minimal COP's were measured using 35–50 V and 6–10 μs wide pulses with approximately 10% duty cycle. All repetition rates (from 10 kHz–2 MHz) were adjusted to yield 4–6 W average pulse power measured on the tube. Recent runs have shown even higher COP's without the use of heater power.

Figure 5 shows an example of the instantaneous COP calculated using the DS analysis method from a recent run. To prove that this COP is stable the stimulation parameters were held constant for 4 h. This latter result is shown in Fig. 5(b). Using the method similar to that used last year is used to calculate the COP, we get significantly larger results. It is also important to note that the absolute LENR powers (Qreaction) are significantly larger than seen earlier. We also

Table 1. Summary of COP calculations from steady-state stimulation runs.

Temperature/°C	COP: IPB2-33	COP: IPB2-74	COP: IPB1-45	COP: IPB1-48
250	1.27	1.14		
275	1.4	1.15	1.11	1.13
f300	1.25	1.13	1.11	
325	1.26	1.09	1.08	1.27
350	1.05	0.94		
400	1.00	.89		

found that the best COP's were achieved between 250 and 350°C, confirming the results that were reported earlier.

The active tube, whose results are presented in Fig. 5, was removed from service at Brillouin's laboratory during December 2017, and placed in service at SRI in a different reactor during April 2018 and showed similar results. These latter plots are shown in Fig. 6.

4. Conclusion

LENR can produce thermal power when Ni and other metal-coated tubes are stimulated using fast rise-time pulses. These experiments were operated in H_2 gas from 200 to 600°C. Comparative thermal measurements were performed between heater-only power and heater and pulse power. These runs were performed in isoperibolic calorimeters operated in power compensation mode, where the heater adjusts its power to keep the inner and outer temperature-difference constant. Over 500 runs were performed on over 70 different Ni-coated tubes. Additional tubes were also tested for other experimental purposes. Recent efforts were spent optimizing tube design, stimulation protocols, calorimeter design, and calorimetric analysis methods. The accuracy and precision of these recent results have been considerably better than those reported earlier.

Reactor tubes can be transported between different laboratories and using different reactors to ta achieve very similar positive results.

Acknowledgements

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