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2  
3 METHOD FOR DETERMINING A TURBINE PUMP RPM PROFILE

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5 STATEMENT OF GOVERNMENT INTEREST

6 The invention described herein may be manufactured and used  
7 by or for the Government of the United States of America for  
8 governmental purposes without the payment of any royalties  
9 thereon or therefore.

10  
11 BACKGROUND OF THE INVENTION

12 (1) Field of the Invention

13 The present invention relates generally to underwater  
14 projectile launch systems, and more particularly to a method for  
15 determining an rpm profile for a turbine pump based on a pulse  
16 train obtained during a pump test.

17 (2) Description of the Prior Art

18 Turbine pumps are typically used to launch a projectile,  
19 such as a torpedo, from a submerged tube. In order to test for  
20 the proper operation of the pump, measurements of the pump's rpm  
21 are taken during a test firing and compared to performance  
22 specifications. The rpm measurements are derived from a pulse  
23 train obtained by a hall sensor or optical encoder mounted to the  
24 pump. The specific sensor used will depend on the type of pump

1 being tested. As the turbine rotates, the sensor provides one or  
2 more pulses for each rotation of the turbine. The timing of the  
3 pulses, or pulse train, provides the rpm indication. For  
4 example, a sensor providing four pulses per revolution, with a  
5 pulse rate of 16 pulses per second indicates an rpm of 240, i.e.,

$$\left(16 \frac{\text{pulses}}{\text{second}} / 4 \frac{\text{pulses}}{\text{revolution}}\right) * 60 \frac{\text{seconds}}{\text{minute}} = 240 \frac{\text{revolutions}}{\text{minute}} .$$

8 Currently, a frequency-to-voltage converter is used to  
9 convert pulse data to rpm data due to the time varying nature of  
10 the pulse frequency. Appropriate conversion factors are applied  
11 depending on the turbine pump type and sensor configuration.  
12 However, to ensure consistent and comparable results, the  
13 converter must be calibrated for each pump test. Additionally,  
14 it has been found that data acquisition systems used to obtain  
15 the pulse train should a counter-timer that reads the pulses  
16 every 30 milliseconds in order to capture both low frequency  
17 pulses at the beginning of rotation and high frequency pulses  
18 when the pump rotates at maximum speed. This timing results in a  
19 relatively rough frequency verses time curve. Further, spikes  
20 tend to occur at the onset of ramp-up, i.e., when the pump first  
21 begins rotation and rpm's are increasing. Such spikes cause  
22 improper interpretation of the rpm data when included in the

1 pulse data set. Thus any one or all of these factors may result  
2 in an erroneous performance evaluation of the turbine pump.  
3

#### 4 SUMMARY OF THE INVENTION

5 Accordingly, it is an object of the present invention to  
6 provide a method to determine a turbine pump rpm profile, which  
7 does not require equipment calibration for each test.

8 Another object of the present invention is to provide a  
9 method to determine a turbine pump rpm profile, which effectively  
10 eliminates spikes in the pulse train.

11 A further object of the present invention is to provide a  
12 method to determine a turbine pump rpm profile having a smooth  
13 frequency verses time curve.

14 A still further object of the present invention is to  
15 provide a method to determine a turbine pump rpm profile, which  
16 is highly repeatable, with a high confidence level.

17 Other objects and advantages of the present invention will  
18 become more obvious hereinafter in the specification and  
19 drawings.

20 In accordance with the present invention, a method is  
21 provided to determine an rpm profile for a turbine pump based on  
22 a pulse train obtained during a pump test. The method obtains a  
23 pulse count over a fixed time period, preferably every 30  
24 milliseconds, from a computer controlled data acquisition system

1 reading the pulse data from a sensor at the pump. The 30-  
2 millisecond acquisition rate has been found to achieve an  
3 accurate rpm profile throughout the operating range of the pump,  
4 i.e., 0-1200 rpm. Once the pulse train data has been obtained,  
5 the method eliminates ramp-up spikes using a spike elimination  
6 technique, which incorporates previous test data. The method  
7 first compares the spike pulse count to the surrounding pulse  
8 counts and rejects data points responsible for abnormal (in  
9 relation to the previous data) pulse count increases between data  
10 points. The method further rejects data points that lie outside  
11 statistically acceptable pulse rate variations.

12 Once ramp-up spikes have been eliminated, a frequency, or  
13 rpm curve can be generated. Depending on the pump being tested,  
14 the sensor may be a hall sensor or an optical encoder and the  
15 number of rotations per pulse may also vary. The method applies  
16 standard factors to the pulse train appropriate to the pump being  
17 tested in order to convert the pulse train to a rough rpm verses  
18 time curve. The rough curve is then smoothed by first infusing  
19 data points to achieve an acquisition rate of approximately 1000  
20 points per second. The infusion is accomplished by interpolating  
21 between actual data points and equally spacing the infused data  
22 points along the interpolated curve. Preferably, a three-point  
23 interpolation scheme is used. Such a large number of data points  
24 is necessary to then apply any one of many standard, 5<sup>th</sup> order,

1 smoothing processes to the rough curve resulting in the final rpm  
2 curve.

3 Thus, the present invention provides a method to determine  
4 an rpm curve, or profile of a turbine pump system. The method  
5 uses the pulse train directly from the counter-timer of a data  
6 acquisition system in determining the profile. The method does  
7 not use a frequency-to-voltage converter and therefore  
8 calibration is not required for each test. Ramp-up spikes are  
9 eliminated from the data, in a manner which yields repeatable  
10 profiles. A rough curve is generated to which data points are  
11 infused, such that a smoothing process can be applied to the  
12 curve. The resultant rpm profiles based on this method have been  
13 found to have a 98% confidence level and be repeatable to within  
14 2%.

#### 15 16 BRIEF DESCRIPTION OF THE DRAWINGS

17 A more complete understanding of the invention and many of  
18 the attendant advantages thereto will be readily appreciated as  
19 the same becomes better understood by reference to the following  
20 detailed description when considered in conjunction with the  
21 accompanying drawing, labeled as FIG. 1 and showing a flow chart  
22 representation of the method of the present invention.

#### 23 24 DESCRIPTION OF THE PREFERRED EMBODIMENT

1           Referring now to FIG. 1, there is shown a flow chart  
2 representation of method 10 used to obtain a turbine pump  
3 performance profile in terms of a plot of revolutions per minute  
4 (rpm) over time. Method 10 is implemented on a computer 12, such  
5 as a computer used for controlling standard data acquisition  
6 systems and having counter-timer to obtain data. In the  
7 preferred embodiment, the data being acquired at 14 consists of a  
8 pulse count over a fixed time period of 30 milliseconds. Each  
9 pulse corresponds to a fixed degree of rotation of the turbine,  
10 such that the number of pulses over a fixed period of time equals  
11 a certain rotation per time period, which corresponds to the rpm  
12 for that time period. The pulses may be obtained from any number  
13 of well-known sensors, such as hall sensors, electro-optic  
14 sensors, or encoders.

15           It is known in the turbine pump field that pulse counts  
16 obtained by a counter-timer typically exhibit spikes during the  
17 ramp-up period, i.e., as the turbine accelerates. To eliminate  
18 the spikes, each pulse count is compared (at 16) to its adjacent  
19 pulse counts. Using historical test data as a basis, pulse count  
20 data points that show spike-like qualities, i.e., a sharp  
21 increase/decrease in neighboring pulse counts, are replaced with  
22 a count value interpolated between adjacent data points at 18.  
23 Similarly, step 20 replaces pulse count data points that lie  
24 outside statistically acceptable pulse rate variations and those

1 that exceed the physical capabilities of the turbine pump, as  
2 determined from the historical test data and mechanical  
3 properties of the pump. Such data points have been found to be  
4 unreliable and tend to skew the resultant rpm profile.

5 By inputting (at 22) the proper conversion factors for the  
6 sensor type and pump type, a rough rpm verses time curve, or  
7 profile is generated at 24. The pulse count data points obtained  
8 by the sensors may not result in a smooth curve due to sensor  
9 sensitivity to noise and vibration during pump operation, or  
10 spacing and sensor inaccuracies. Normally, a smoothing function  
11 would be applied to the rough rpm curve to obtain a final rpm  
12 profile. However, typical smoothing functions require a large  
13 number of data points. Thus, artificial data points are infused  
14 by interpolating (at 26) between pulse count data points to  
15 obtain interpolated segments and equally spacing (at 28)  
16 artificial data points on each of the segments between pulse  
17 count data points to obtain approximately 1000 data points per  
18 second. For the 30 millisecond pulse count data acquisition rate  
19 of the preferred embodiment, approximately 30 artificial data  
20 points are infused between each pulse count data point.  
21 Interpolation may be by any one of many standard schemes. In the  
22 preferred embodiment, a three-point interpolation is used to  
23 provide a curved segment between the pulse rate data points,  
24 while trying to minimize the computational burden. A smoothing

1 function, preferably a 5<sup>th</sup> order function, is applied (at 30) to  
2 the infused data set to obtain the final rpm profile, which is  
3 plotted (at 32) for turbine pump performance evaluations.

4 The invention thus described provides a method that uses  
5 pulse count data directly to obtain an rpm profile of a turbine  
6 pump, without the need for a frequency-to-voltage converter as in  
7 the prior art systems and methods. Thus, the need for converter  
8 calibration for each test is eliminated allowing for additional  
9 tests within a given time frame and also reducing costs on a per  
10 test basis. The method further provides highly repeatable  
11 results in that ramp-up spikes are effectively eliminated from  
12 contributing to the rpm profile and smoothing techniques can be  
13 applied to the data.

14 Although the present invention has been described relative  
15 to a specific embodiment thereof, it is not so limited. While  
16 the method has been described for determining a turbine pump rpm  
17 profile, the spike elimination and infusion techniques can be  
18 applied to many data sets where the nature of the sensing  
19 instruments results in aberrant spikes and a sparse data set.  
20 Also, as previously noted, the interpolation and smoothing  
21 functions used may be chosen from among many well-known functions  
22 so as to fit the data set.

23 Thus, it will be understood that many additional changes in  
24 the details, materials, steps and arrangement of parts, which

1 have been herein described and illustrated in order to explain  
2 the nature of the invention, may be made by those skilled in the  
3 art within the principle and scope of the invention.

4

1 Attorney Docket No. 80190

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3 METHOD FOR DETERMINING A TURBINE PUMP RPM PROFILE

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5 ABSTRACT OF THE DISCLOSURE

6 A method is provided to determine an rpm profile for a  
7 turbine pump from pulse train data obtained from a sensor at the  
8 pump. The method eliminates ramp-up spikes from the pulse train  
9 by comparing the spike pulse count to the surrounding pulse  
10 counts and replacing data points responsible for abnormal pulse  
11 count increases/decreases between data points with interpolated  
12 values. The method similarly replaces data points that lie  
13 outside statistically acceptable pulse rate variations. A rough  
14 rpm plot is then generated, which must be smoothed to obtain the  
15 final rpm profile. Data points are infused between sensor data  
16 points to achieve an acquisition rate of approximately 1000  
17 points per second. The infusion is accomplished by interpolating  
18 between sensor data points and equally spacing the infused data  
19 points along the interpolated curve. A smoothing function is  
20 then applied to the infused data set.

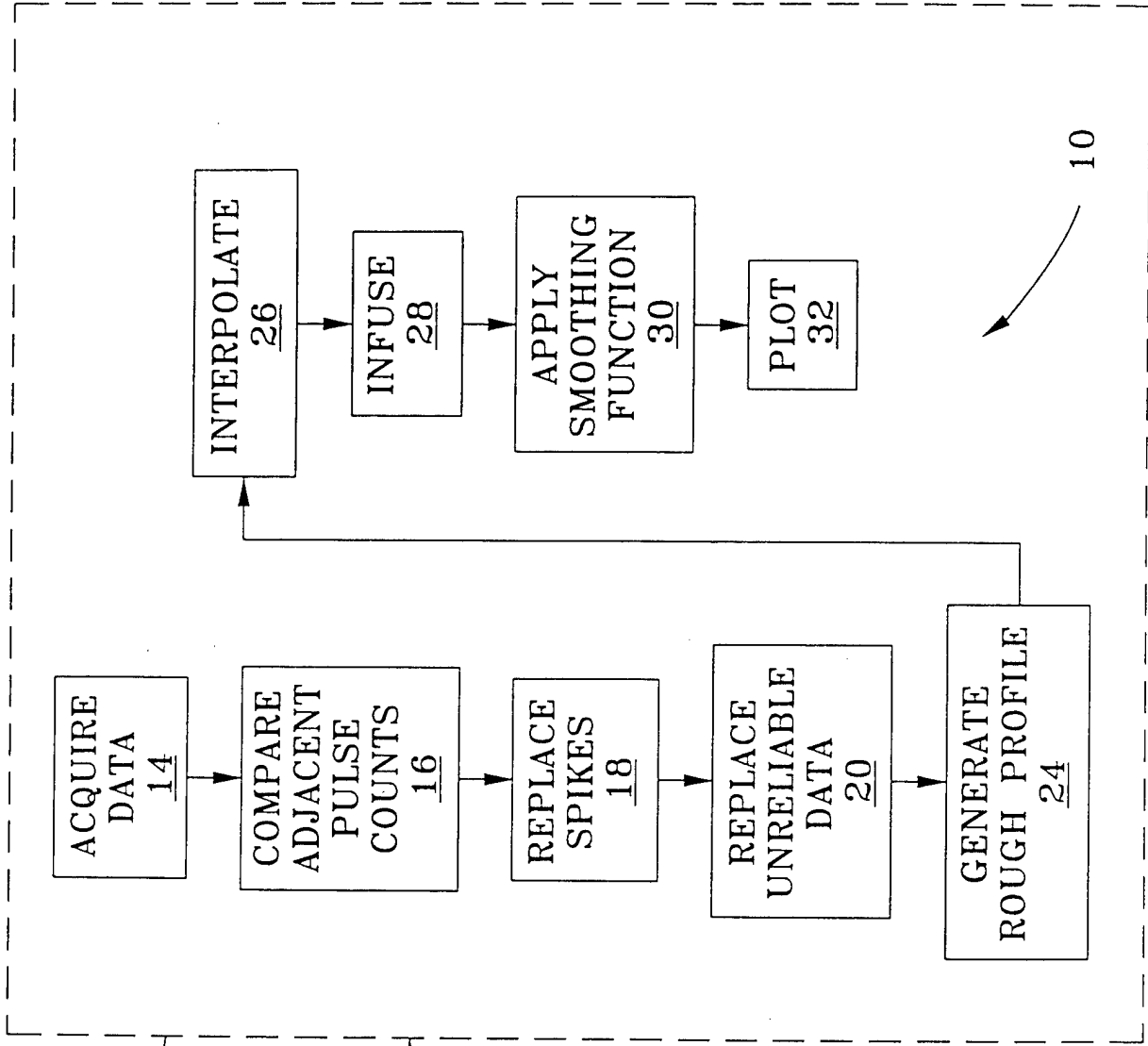


FIG. 1