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Experimental Measurement of ROV Tether Tension

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Abstract

In the undersea operation of a tethered ROV system, the pilot's ability to control precisely the ROV is often limited by disturbance forces generated by drag due to currents that act either directly on the ROV or indirectly on the ROV through the tether. The objective of this research, which was conducted at the Monterey Bay Aquarium Research Institute (MBARI), was to characterize the magnitude and dynamics of tether forces by measuring them during operation. To achieve this, a tether tension sensor and data logging system were developed. This system was used to measure the forces in the tether of MBARI's ROV, an ISE Hysub ATP40. Initial results, which are presented in the paper, indicate that in certain operating regimes the tether tensions can be quite large, often as high as 600 pounds. Time histories and spectral content typical of the data gathered are presented.

1 Introduction

Tethered underwater vehicles continue to play an increasingly important role in ocean science and industry. Contemporary with their more widespread use, have been increased efforts to understand and characterize tethered underwater vehicle dynamics and performance. The dynamics of towed vehicle systems, such as ARGO/JASON at the Woods Hole Oceanographic Institution, have been researched extensively in recent years. Simulation studies and experimental work have shown tether dynamics to be very significant in the dynamics of towed vehicle systems [1].

The work presented in this paper deals with lightweight tether systems, where the tether connecting the support ship and ROV is not used for towing or positioning the vehicle, but rather to transmit power and signals only. Even though tethers for these systems are designed to be neutrally buoyant and to operate with sufficient slack so that minimal disturbance loads are transmitted to the vehicle, in reality, this is often not the case. Under actual operating conditions, ROV pilots have observed large disturbance forces due to tension build up from currents acting on the tether. Static computer models developed at MBARI and computer models in the literature [2][3] also suggest that these tether disturbances can be significant, thereby limiting the pilot's ability to position precisely the ROV.

An understanding of tether forces and the capability to measure them is important for several reasons. First, if tether force can be measured, different schemes for deploying the tether (e.g. use of a clump weight, different float placement, etc.) can be evaluated. Second, the tradeoff between tether length and disturbance force can be explored. This is important information for the design of future tethered vehicles. Third, to design vehicle control systems with good disturbance rejection capability, the characteristics of the disturbance forces must be well understood.

The results presented in this paper represent the first documentation of tether force mea-

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surements for an ROV operating with a long, lightweight tether system. Ongoing extensions to the research presented here involve using tether tension measurements in a closed loop control scheme to cancel tether disturbances on the vehicle. The following sections of the paper describe the tether tension sensor hardware that was developed and the experimental results that were obtained using the sensor to measure tether force during operation of the MBARI ROV.

2 Experimental Setup

2.1 Sensor Hardware Description

The tether tension sensor's function is to measure the tension in the ROV tether. This is done using a mechanism which translates the tension in the tether into a force which acts normal to the tether. This "normal" force is measured using a strain gage-based load cell designed specifically for this application. A schematic showing the function of the sensor mechanism is shown in Figure 1.

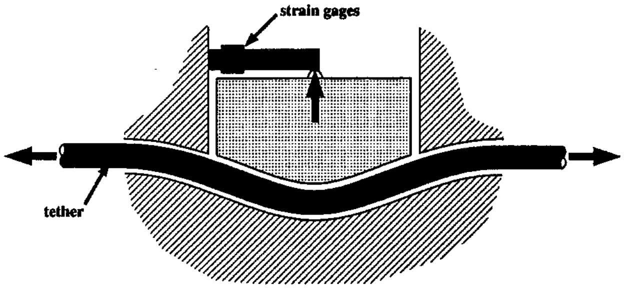

Figure 1: **Tether Tension Sensor Mechanism Schematic**

The strain gage bridge output signal is amplified approximately 500 times and filtered with a 10 Hz double-pole filter using low-power op-amp circuitry, which is mounted on a piggyback board to the data acquisition computer. In its present configuration, the sensor has a range of 0 to 700 pounds of tether tension.

The data acquisition computer chosen for this application was the Tattletale Model V made by Onset Computer Corp. The Model V was chosen primarily because of its small size and reasonable cost. The Model V is based on the Hitachi 6303 CPU chip. The Model V has an 11-channel, 10-bit A/D converter and 17 digital I/O lines. With the 5x1 memory expansion board, the Model V has over 150K of RAM available for data storage. For developing and executing data acquisition programs, the Tattletale has a BASIC interpreter on board.

The rechargeable Ni-Cad batteries supply enough power to operate the computer, strain gages, and electronics for up to 16 hours of continuous operation. The batteries and Tattletale are housed in a pressure-proof container which is fastened to the mechanical portion of the sensor.

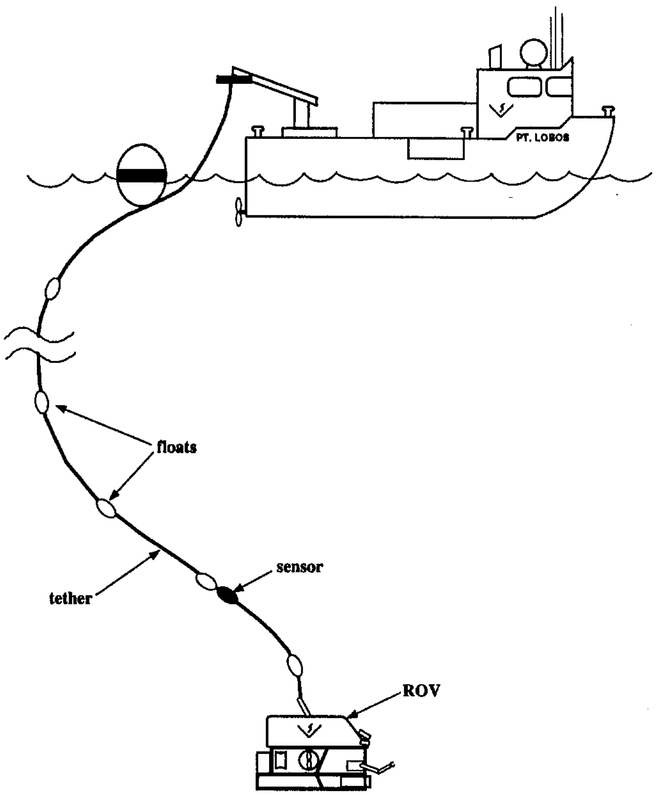

Figure 2: **ROV System Schematic**

2.2 Vehicle Description

The MBARI ROV is an ISE Hysub ATP40. It is capable of producing 700 pounds of thrust in the forward direction and 400 pounds of thrust in the lateral and vertical directions. The vehicle is tethered to the support ship by a 1450 foot long, 0.9 inch diameter umbilical which provides power and control signals to the ROV. Syntactic foam floats are attached to the tether at 45 foot intervals to make the tether neutrally buoyant. At the surface, the tether is supported by large buoys which provide some compensation for the heaving of the ship. The data presented here were taken with the tether deployed at its full length and with the tension sensor mounted 75 feet above the ROV. Figure 2 shows a schematic of the vehicle system.

3 Experimental Results

The data presented here were recorded on two dives which took place on 10 September 1990 and 12 September 1990. On 10 September, the ROV was being used to make observations on the wall and floor of Monterey Canyon. Once at depth, the ROV operated in the 1100-1200 foot depth range most of the dive. On 12 September, the ROV was being used to make mid-water observations. The ROV operated at depths ranging from 400 to 1200 feet, with the majority of the dive taking place at around 1000 feet.

Figures 3 through 6 show time histories of the tension measurements taken at different points in the 10 September dive. Figure 7 shows a plot of the power spectral density of the tension measurements taken early in the 10 September dive along with the window of data used to calculate the PSD. Figures 8 through 10 show time histories of the tension measurements taken at different points in the 12 September dive.

4 Discussion of Results

4.1 10 September Dive

Figure 3 shows the tether force measurement during the beginning stages of the descent at about 200 feet. This shows the transient nature of the forces measured. As the DC component of the force increases, the amplitude of the oscillating component tends to increase as well. Figure 4 shows the tether forces measured when the vehicle was at about 750 feet. Notice the oscillatory nature of the forces measured. It is speculated that at this point in the dive, the tether was taut due to its being dragged through the water and that the oscillations are due to the heaving of the ship and the buoys attached to the tether at the surface.

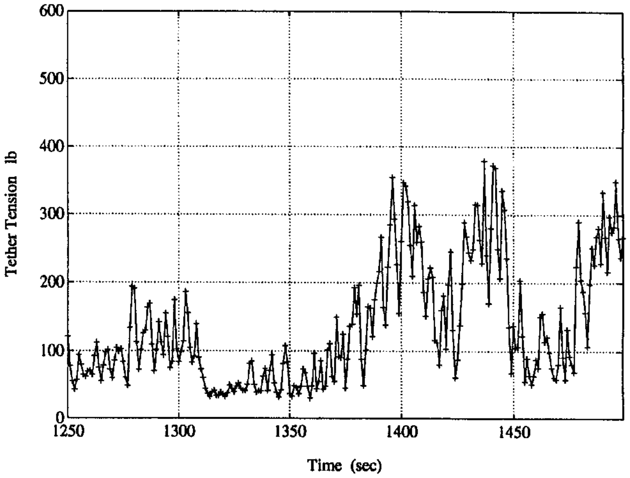

Figure 3: **Tether Tension vs. Time**

10 September dive, 200 foot depth, descending.

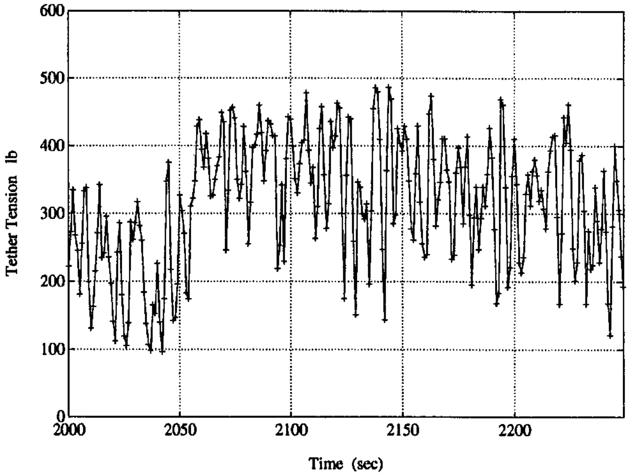

Figure 4: **Tether Tension vs. Time**

10 September dive, 750 foot depth, descending.

Figure 5 shows the time history of the peak tether force observed during the 10 September dive. At this point in the dive, the ROV was at 1200 feet and was maneuvering to locate a concrete marker on the floor of the canyon. Again, the tether was taut due to its limited length and its being dragged through the water column. The sudden spike in tether tension presumably was caused by the vehicle reaching the limits of its range from the ship.

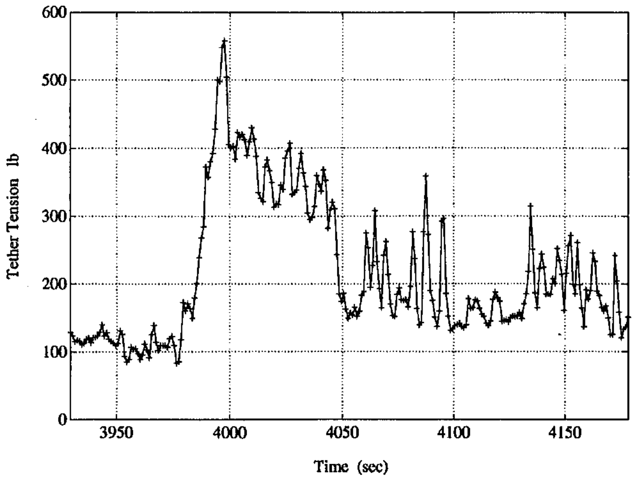

Figure 5: **Tether Tension vs. Time**

10 September dive, 1200 foot depth, searching floor for marker.

Figure 6 shows a plot of the tether force measurements taken later in the dive with the ROV in the 1100 to 1200 foot depth range. At this point in the dive, the ROV was on station and was not dragging the tether through the water. It is assumed that the tether forces were generated primarily from the currents acting on the tether. Throughout the latter half of the dive, tensions were between 50 and 200 pounds and fairly steady.

To determine the frequency content of the tension forces measured, the power spectral density of the tension signal was calculated using the time history data from the first part of the dive. The data was sampled at 1 Hz and 13 streams of 256 data points were used to calculate 13 PSDs which were then averaged. Figure 7 shows the resulting plot of the power spectral density. Notice the spike at .135 Hz. This corresponds to a natural period of 7.4 seconds and can be attributed to the heaving of the ship and lead buoy. Figure 7 also shows the time window of tether tension data used to calculate the PSD.

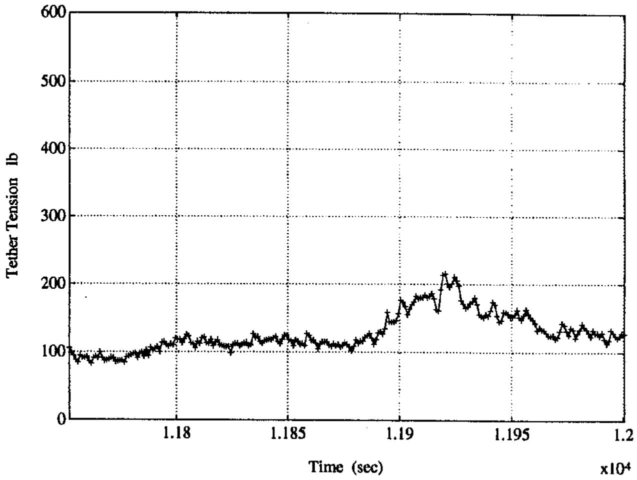

Figure 6: **Tether Tension vs. Time**

10 September dive, 1100 foot depth, on station.

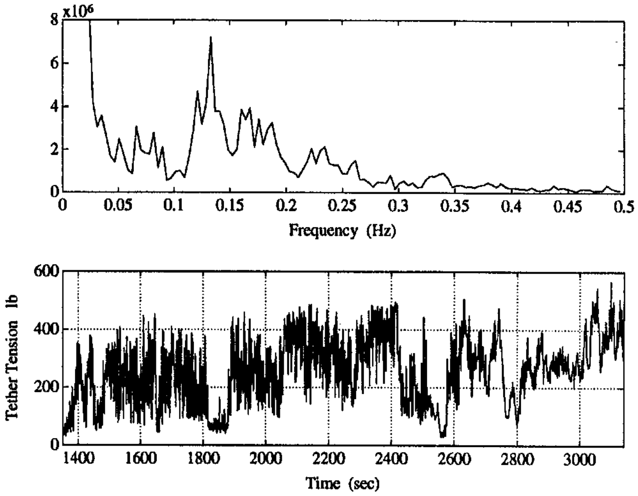

Figure 7: **Power Spectral Density of Tether Tension Data**

10 September dive, during descent.

4.2 12 September Dive

Data taken during the dive of 12 September (mid-water observations) was quite similar to the data taken in the latter half of the 10 September dive (see Figure 6). Tensions were typically below 200 pounds and not very dynamic when compared to the data from the first half of the 10 September dive. Figure 8 shows time history data taken early in the dive with the ROV operating at about 550 feet (notice the change in scale of the tension axis). Tension levels are around 100 pounds and fairly steady. Figure 10 shows the data taken towards the end of the dive with the ROV at approximately 1000 feet. Again, the tension levels are low and relatively unchanging.

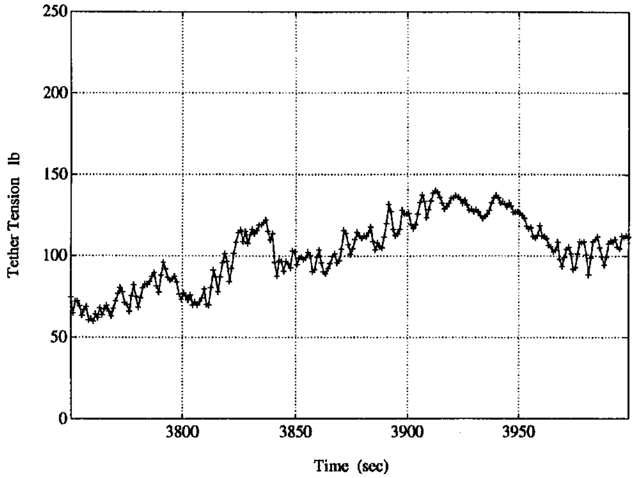

Figure 8: **Tether Tension vs. Time**

12 September dive, 550 foot depth, slowly descending.

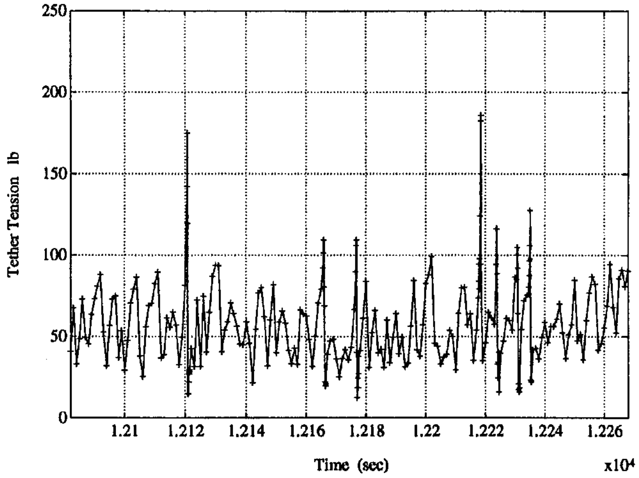

Figure 9: **Tether Tension vs. Time**

12 September dive, 1175 foot depth, on station, rough seas.

During the latter part of the dive some interesting dynamics were observed in the data at several points. Figure 9 shows data that are fairly calm with occasional sharp spikes. It is speculated that these spikes are due to a combination of things. First, the ROV was operating at 1175 feet which is near its depth limit due to tether length. Second, during the latter portion of the dive, the seas became significantly rougher than those observed during the first half of the dive and during the dive of 10 September. While smaller in magnitude, these spikes have higher frequency components (perhaps as fast as 1 Hz) than those observed in the 10 September dive data. A more accurate characterization of this effect will require further experimentation.

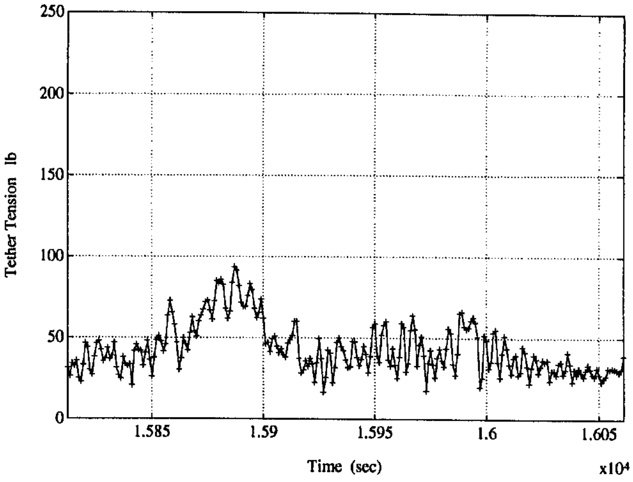

Figure 10: **Tether Tension vs. Time**

12 September dive, 1000 foot depth, on station.

5 Conclusions

The results presented in this paper are the first measurements of tether tension for an ROV operating with a lightweight tether system. Initial experiments show that in its present light tether configuration, the MBARI ROV experiences tether force disturbances of very significant magnitude which makes the vehicle difficult to control. These results are a preliminary validation of the operational experience of ROV pilots and computer models which also suggested that these disturbances were significant. Further experimentation will give additional insight into tether forces and their affect on lightweight tethered ROV systems.

6 Acknowledgements

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