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**MANOEUVRES IN ICE OF CCGS HENRY LARSEN  
PERFORMED DURING THE 1997 VOYAGE TO VOISEY'S BAY**

**TR-1997-20**

**Piotr Waclawek**

**July 1997**

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<b>SUMMARY</b>  In March 1997, the Canadian Coast Guard invited the Institute for Marine Dynamics to participate in a Probe of the area around Voisey's Bay, Labrador. The ship to be used for the study was the <i>C.C.G.S. Henry Larsen</i> . The purpose of the probe was to provide data relevant to the Environmental Impact Study, required for the development of the mining operations in the area. IMD had two roles in the project. One was to provide measurements of ice thickness, temperature profiles and salinity. The other was to provide data on the performance of the ship during manoeuvres in open water and ice. Another important function for IMD was to observe and understand the captain's decisions for navigating through various ice formations. IMD was pleased to be invited to participate in this probe, since we have recently begun a major research project related to ship manoeuvring in ice, and this trip provided very valuable full scale data, essential for the validation of the analytical models of ship performance.				
<b>ADDRESS</b>	National Research Council Institute for Marine Dynamics P. O. Box 12093, Station 'A' St. John's, Newfoundland, Canada A1B 3T5			

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## MANOEUVRES IN ICE OF CCGS HENRY LARSEN PERFORMED DURING THE 1997 VOYAGE TO VOISEY'S BAY

### 1.0 INTRODUCTION

In March 1997, the Canadian Coast Guard invited the Institute for Marine Dynamics to participate in a Probe of the area around Voisey's Bay, Labrador. The ship to be used for the study was the *C.C.G.S. Henry Larsen*. The purpose of the probe was to provide data relevant to the Environmental Impact Study, required for the development of the mining operations in the area. IMD had two roles in the project. One was to provide measurements of ice thickness, temperature profiles and salinity. The other was to provide data on the performance of the ship during manoeuvres in open water and ice. Another important function for IMD was to observe and understand the captain's decisions for navigating through various ice formations. IMD was pleased to be invited to participate in this probe, since we have recently begun a major research project related to ship manoeuvring in ice, and this trip provided very valuable full scale data, essential for the validation of the analytical models of ship performance.

Two major groups of data were collected during this voyage, namely:

- the ship performance data, and
- ice condition data.

The assessment of the ship manoeuvring trials in ice cannot be achieved without addressing the conditions in which the trials were carried out. The research of ice is, however, a very distinct entity from ship performance, and comprises many components that will be analyzed in many different fields of research. A separate report (TR-1997-26) that addresses the ice study is therefore a part of this research and must be referenced in order to obtain the full picture of the events described here.

The structure and display of data from turning circle and zig-zag manoeuvres is the main purpose of this report. Further analysis needs to be done to relate these data to the environmental conditions. Such a study is needed to develop an algorithm for the numerical simulation of the Navigation of Ships in Ice.

## **2.0 THE SCENARIO**

The ship's main area of operation was set North-East of the Hen & Chicken group of islets, some 50 miles from Nain. The ice conditions typical at the time of the trial were rubble, new sea ice 1-2m thick, with frequent shearing zones. This ice motion was subject to surface current, tides and wind forces acting mostly in non-uniform directions. Occasionally icebergs or multi-year ice appeared, driven by the Labrador current. The ice motion in this area is greatly affected by the presence of multiple islands, islets and rocks that also create pressured ice.

The vessel was manoeuvring in this area using its Wartsila air bubbler system. The system proved to be very effective, especially when the ice was covered with snow. All manoeuvres presented in this report were carried out with the bubbler on, otherwise - for the ice of approximately 1.3m thick- the ship would stop during the trial. The roll stabilization and heeling system fitted on the ship was not used during the trial.

## **3.0 METHODOLOGY OF MANOEUVRING TRIALS IN ICE**

A method of collecting the manoeuvring data in open water was adopted and synchronised with the assessment and measurements of the ice in the areas where the manoeuvring tests were carried out. A simplified algorithm was used to convert the position data of the ship (recorded by the GPS receiver in the geographic units) to XY position (in metres). It is deemed sufficiently accurate for the present data analysis, however, the original data are available if more precise conversion need to be applied. In short, the algorithm addresses more the relative data (latitude and longitude), leaving a room for the error when related to the Datum(s) used in different stereographic definitions of the Earth.

### **3.1 Standard Manoeuvres Data Collection**

The ship manoeuvring trials data set consist of the following time series:

- global time,
- latitude,
- longitude,
- ship speed,
- heading,
- engines rpm, and
- rudder angle.

To this end the ship position (latitude and longitude), heading and speed has been collected from the GPS receiver, while the rudder deflection, and shafts rpm readings were taken from the corresponding signals to meters available on the bridge. The data were managed and stored in an on-board PC. This system was designed, arranged and installed when the vessel stayed in St. John's harbour, prior to the start of the voyage. This work was a part of IMD's MSAT project, in which the above-mentioned data was collected remotely via an MSAT satellite connection. The analogue to digital conversion formulae were adopted from this project, too.

### **3.2 Measurements of Ice Conditions**

Two systems were used for recording the ice data:

- video cameras for the visual ice description , and
- direct measurement for its physical parameters.

The video tapes were used to record the visual description of ice and the time when the tests were done. Two cameras were mounted on the ship: one on the wheel-house allowing for a bow view, and another on the ship shoulder (starboard) directed at the broken ice right beneath it. The synchronisation of these data and the ship manoeuvring data has been easily made since the later were collected on the basis of the global time (Greenwich Time).

The direct ice measurement (salinity and temperature) was performed on the ice cores that were taken after the manoeuvre was finished. This procedures are described in detail in IMD Report #TR-1997-26.

### **4.0 THE MANOEUVRING MATRIX**

Two basic type of manoeuvres were proposed for the Probe:

- turning circles, and
- zig-zags.

The test program was drafted with the understanding that the ice conditions, geographic position, as well other parameters would play the major role in its realisation. These parameters were not well known prior to the voyage to the Voisey's Bay area. The motion and strength of ice are greatly affected by the presence of tides, wind, currents and many rocks and islets. Therefore, a number and type of standard manoeuvres to be performed was a function of the ice conditions as well as the ship's daily activities.

#### 4.1 Data Organization

The data collected during the trip remain an important base for future applications, especially for validation process that must follow any modelling or simulation. An access to it as well as root information are essential for any future research. In anticipation of the future use, the way the data is stored has been elaborated to make it fully functional and useful.

All meaningful data has been stored within the Matlab environment that allows us to organize it into a compact structure (struct array) of size 11x11 named **larsen** (and file **larsen.str**). Each element of the structure consists of one session of collecting data (encapsulated within a file during the trial) with a name corresponding to the original file. The numbers that appear in the name consist of several doublets, which present (in an ascending order):

hours,  
minutes,  
days,  
month.

During a particular session more than one test was sometimes recorded. In the structure it was recognized by adding a few letters/numbers at the end of the file name. Therefore

'a09502403\_tcp20'

means a turning circle trial for the rudder at 20 degrees to starboard (p- positive), extracted from the file recorded at 9:50 on April 3<sup>rd</sup>.

There were eleven sessions of data collected and stored in eleven rows of the structure, whereas within some of these sessions a total number of eleven tests were performed.

Each element of the structure has identical following fields:

'name'  
'info'  
'raw\_data'  
'mod\_data'  
'position'  
'circle'  
'ship\_speed'

where:

in 'name' - the name of the file is stored,

info' consists of the following self-explanatory fields:

description:

general:

ice:

wind:

geo:

longitude:

latitude:

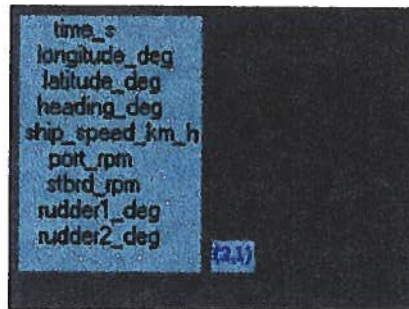
init\_head:

init\_speed:

knots:

m\_s:

The raw\_data and mod\_data store the time series as collected (raw\_data), and -if necessary- extracted from this raw data (mod\_data).



**Figure 1 The recorded time series**

## 5.0 LIST OF TRIALS

The total number of the turning circle manoeuvres successfully executed are shown below. In the figure the name of the file or test is combined with the following test description:

'tc' - turning circle

'p' - positive (starboard)

'n' - negative (port)

number (20 or 35) for the rudder angle.

The display of related time series and some other parameters are presented in Appendix A.

name = a09502403_top20 longitude = 56.4762 deg. latitude = 59.9993 deg. knots = 4.9676 knots init_head = 166 deg. circle = D = 967.7 m (6.2)	name = a09502403_top20 longitude = 56.4655 deg. latitude = 60.0146 deg. knots = 7.6324 knots init_head = 188 deg. circle = D = 748.6 m (6.3)	name = a09502403_top20half longitude = 56.4577 deg. latitude = 59.9999 deg. knots = 7.959 knots init_head = 130 deg. circle = D = 913.1 m (6.4)	
name = a10192903_top35 longitude = 56.7268 deg. latitude = 60.131 deg. knots = 15.6317 knots init_head = 261 deg. circle = D = 350.8 m (7.2)	name = a13430104 longitude = 56.5832 deg. latitude = 60.0153 deg. knots = 8.7743 knots init_head = 149 deg. circle = D = 1368 m (6.3)	name = a13482703_top35 longitude = 56.5624 deg. latitude = 60.2588 deg. knots = 10.8477 knots init_head = 265 deg. circle = D = 471.5 m (7.2)	name = a13482703_top35 longitude = 56.5625 deg. latitude = 60.2673 deg. knots = 9.6436 knots init_head = 249 deg. circle = D = 349.3 m (7.3)
name = a13482703_top20 longitude = 56.5666 deg. latitude = 60.2772 deg. knots = 7.1598 knots init_head = 255 deg. circle = D = 877.6 m (7.4)	name = a13482703_top20 longitude = 56.5499 deg. latitude = 60.2894 deg. knots = 8.9687 knots init_head = 208 deg. circle = D = 684.7 m (7.5)	name = a13482703_top352 longitude = 56.4881 deg. latitude = 60.2597 deg. knots = 2.7808 knots init_head = 144 deg. circle = D = 734.7 m (7.6)	name = a13482703_top353 longitude = 56.4963 deg. latitude = 60.2721 deg. knots = 8.9093 knots init_head = 275 deg. circle = D = 673.2 m (7.9)
name = a13482703_top352 longitude = 56.4948 deg. latitude = 60.2862 deg. knots = 6.0475 knots init_head = 326 deg. circle = D = 931 m (7.10)	name = a14020104_top20 longitude = 56.5758 deg. latitude = 60.0137 deg. knots = 9.3467 knots init_head = 222 deg. circle = D = 1009 m (8.2)	name = a14020104_top35 longitude = 56.5722 deg. latitude = 60.008 deg. knots = 10.0216 knots init_head = 84 deg. circle = D = 421.1 m (8.3)	name = a14020104_top35 longitude = 56.5798 deg. latitude = 60.0081 deg. knots = 7.2786 knots init_head = 31 deg. circle = D = 750.2 m (8.4)
name = a15393003 longitude = 56.4875 deg. latitude = 60.0021 deg. knots = 9.8758 knots init_head = 173 deg. circle = D = 627.4 m (11.5)			

Figure 2 List of Turning Circles

**Table 0.1 Turning Circles, Initial Parameters**

#	name	rudder angle [deg]	approach speed [knots]	ideal tc diameter [m]
2,2	a09502403_tcp20	20	4.97	967.7
2,3	a09502403_tcn20	-20	7.53	748.5
2,4	a09502403_tcp20half	20	7.96	913.1
3,2	a10192903_tcn35	-35	15.63	350.8
6,1	a13430104	-20	8.77	1368
7,2	a13482703_tcp35	35	10.85	471.5
7,3	a13482703_tcn35	-35	9.64	349.3
7,4	a13482703_tcp20	20	7.16	677.6
7,5	a13482703_tcn20	-20	8.97	684.7
7,8	a13482703_tcn352	-35	2.78	734.7
7,9	a13482703_tcn353	-35	8.91	673.2
7,10	a13482703_tcp352	35	6.05	931
8,2	a14020104_tcp20	20	9.35	1009
8,3	a14020104_tcn35	-35	10.02	421.1
8,4	a14020104_tcp35	35	7.28	750.2
11,1	a15393003	35	9.88	627.4

Appendix  
rpm  
150  
160  
160  
172  
165  
165  
165  
165  
160  
160  
112.5  
115  
165  
165  
160  
165

The zig-zag manoeuvres proved to be of lesser importance, as their realization was hardly possible in a uniform ice configuration. In addition, this type of manoeuvre in rubble ice has much less pronounced kinematic parameters, therefore the standard analysis developed for open water manoeuvres could be used. The total number of the zig-zag manoeuvres is presented in Fig. 2.

In the name 'zz' stands for zig-zag, and the following number shows the rudder setting (10/10 or 20/20). The display of related time series and some other parameters are presented in an Appendix B.

110  
↓  
180

vs

115, 150, 160, 165, 170

6.05  
8.91

n

name = a10542903_zz10 longitude = 56.7308 deg. latitude = 60.1428 deg. init_head = 115 deg.	(4.2)	name = a11532803 longitude = 56.3813 deg. latitude = 60.1284 deg. init_head = 320 deg.	(5.3)
name = a13482703_zz10 longitude = 56.5622 deg. latitude = 60.3004 deg. init_head = 346 deg.	(7.0)	name = a13482703_zz20 longitude = 56.5217 deg. latitude = 60.2953 deg. init_head = 178 deg.	(7.7)
name = a13482703_zz202 longitude = 56.5021 deg. latitude = 60.2885 deg. init_head = 332 deg.	(7.11)	name = a14033003 longitude = 56.5607 deg. latitude = 60.0803 deg. init_head = 94 deg.	(9.1)
name = a14113003 longitude = 56.5375 deg. latitude = 60.0447 deg. init_head = 151 deg.	(10.1)		

Figure 3 List of Zig-zags

### 5.1 Turning Circle Manoeuvres

The actual ship's trajectory during the full turning circle manoeuvre rarely has a regular shape. In addition, neither the ship's speed nor the change of heading distinctly marks the beginning or end of the manoeuvre. Fortunately the collected data contain the rudder's deflection angle and that is used to determine the beginning and end of a test. For statistical purposes the patches representing the area (work) encircled by the ship trajectory are shown. The area of the patch is used to determine the radius of the equivalent steady state circle in constant ice conditions. This is also shown plotted. The level of variation between the trajectories for individual manoeuvres is relatively high, but this is due to the local ice conditions for each test. In ice, contrary to the same manoeuvre in open water, there is no time-variant motion at the beginning of the turning circle. Since the motion of the ship in rubble ice depends on the instantaneous ice conditions, such a representation can be useful in further analysis, since the turning diameter can be instantaneously referred to the actual trajectory pattern.

## 5.2 Zig-zag Manoeuvres

The 10/10 zig-zags and 20/20 zig-zags were recorded in different ice conditions. The ship trajectory, heading, speed and rudder deflection are presented in this section. In analyzing the data, it was quickly found that it is quite difficult to estimate the correlation between the rudder setting and the ship's heading, which is of course a predictable relationship in open water zig-zag trials. It may be possible to analyze the zig-zag manoeuvres in ice, if the data are carefully checked and correlated with the instantaneous ice configuration recorded on the shoulder and bow mounted videos. In any case, the analysis of the zig-zag experiments in ice were not as useful as the ones conducted for the open water trials, therefore the zig-zags were eventually dropped from the trial manoeuvring matrix.

## 6.0 CONCLUSIONS

The trial showed that the ice conditions experienced in the approaches to Voisey's Bay, Labrador are very dynamic and will pose a severe hazard to navigation, if shipping is carried out in the winter months. Average turning radii in ice varied between 350m and 930m for a full rudder deflection (35 degrees), and between 677m and 1368m for the rudder angle deflected to 20 degrees. The ice parameters are amongst the main factors causing this large discrepancies and the detailed analysis is there necessary.

The effect of the bubbler system was acknowledged and appreciated but it has not been a subject of the research. It would have required a lighter ice regime to assess its performance in quantitative terms.

The biggest problem for ship manoeuvring was the non-uniformity of the ice conditions. The success in carrying out a manoeuvre depended very much on the local ice conditions during the turn. The dynamics of the ship-ice interaction could overwhelm the ability of the rudder to control the ship. This meant that large amounts of space are required to ensure safe navigation, since the amount of space needed to execute a smooth manoeuvre is much larger than the amount of space needed to make the equivalent turn in open water.

## **7.0 RECOMMENDATIONS**

The ice formation process and its motion in the vicinity of Voisey's Bay has yet to be evaluated more thoroughly in view of the economics and safety of navigation in the area. The Probe delivered enough data though to recognize the complexity from the navigation stand point. The data gathered during the navigation trials -useful for the validation and more in-depth analysis - are therefore a priceless source of information. The information is, however, limited to the time of the trial and represents only a small sample of the possible ice and environmental conditions over the years. It will be therefore recommended and even necessary to collect more data from similar trips in the future, when the ice formations will differ from those of Probe1, to get a larger data bank of the area.

From the research point of view, a performance of the same ship in more consistent ice conditions needs to be studied. Level ice, in particular, would be of great importance. It would allow us to conduct a comparative study on a better defined set of environmental conditions that can be later reproduced in the ice tank, for example.

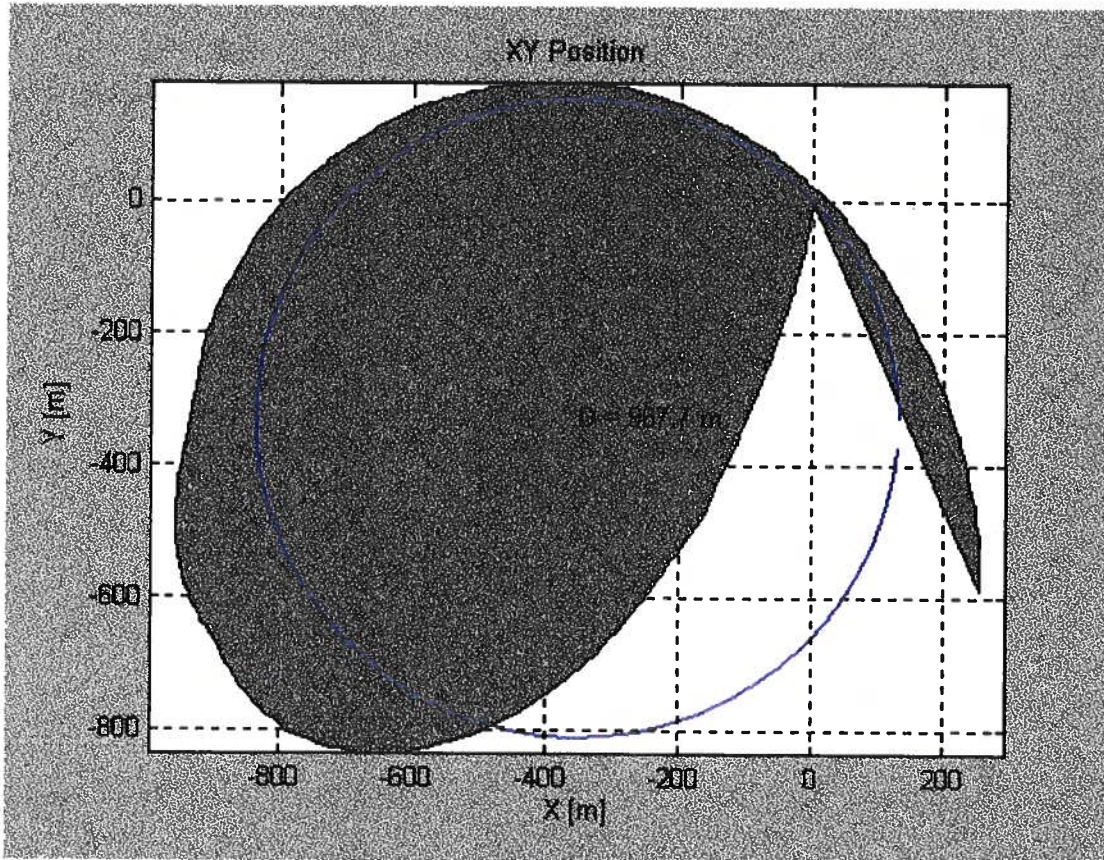
## **8.0 ACKNOWLEDGMENTS**

The voyage and sojourn on board of 'Henry Larsen' was very efficiently and professionally organized by the Canadian Coast Guard crew. IMD values highly the effort of Dan Shea - the CCG Project Manager and Captain Perry Stairs - coordinator of probe research activities, for managing this research trip. The author would also like to express a great appreciation for the help and collaboration offered by the skipper of 'Henry Larsen', Captain Stu Klebert.

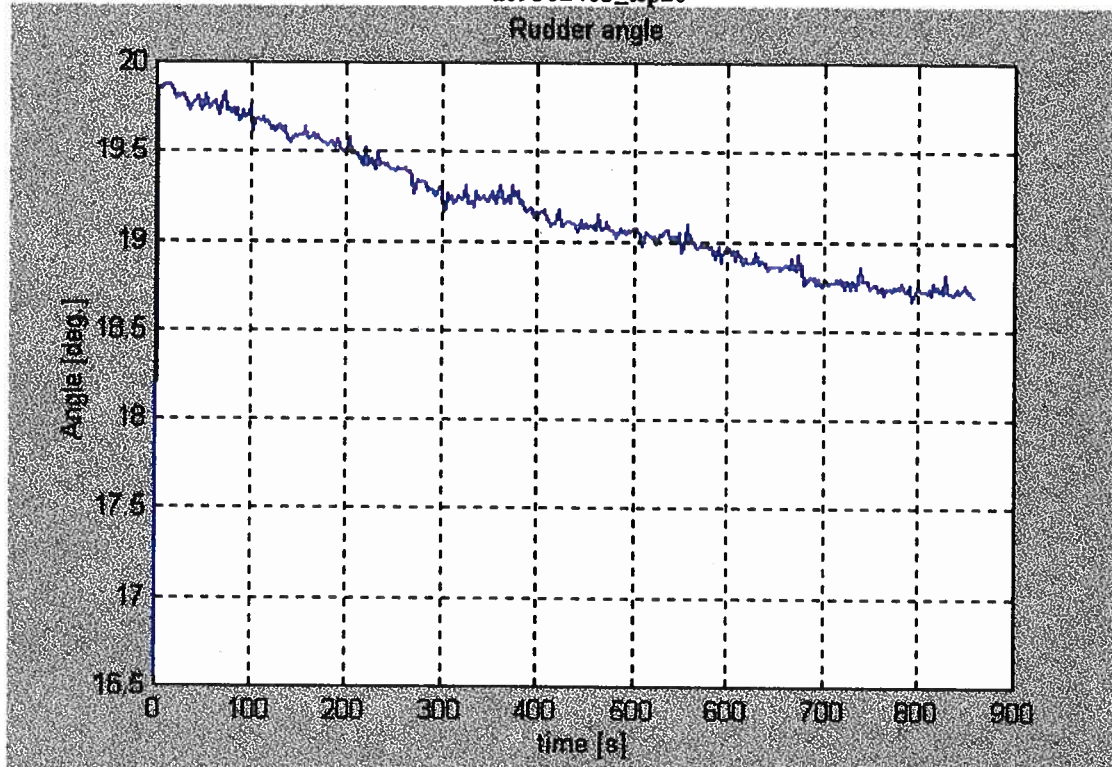
## **Appendix A**

### **Time Series of Turning Circles**

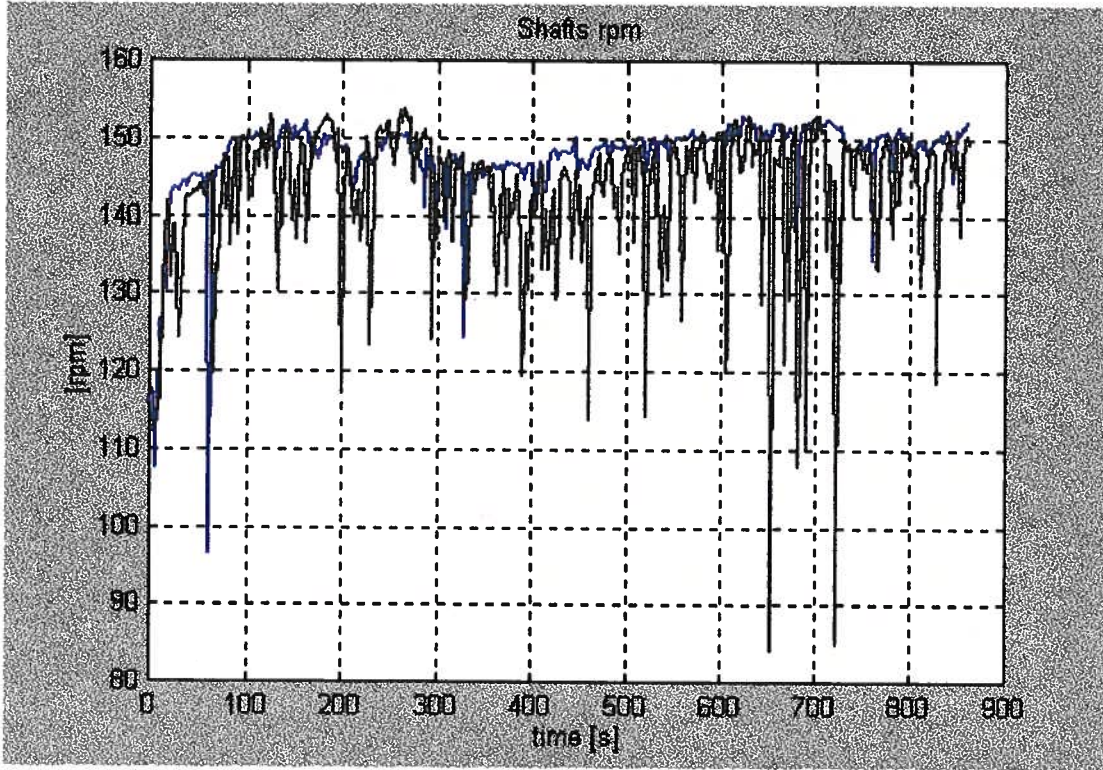
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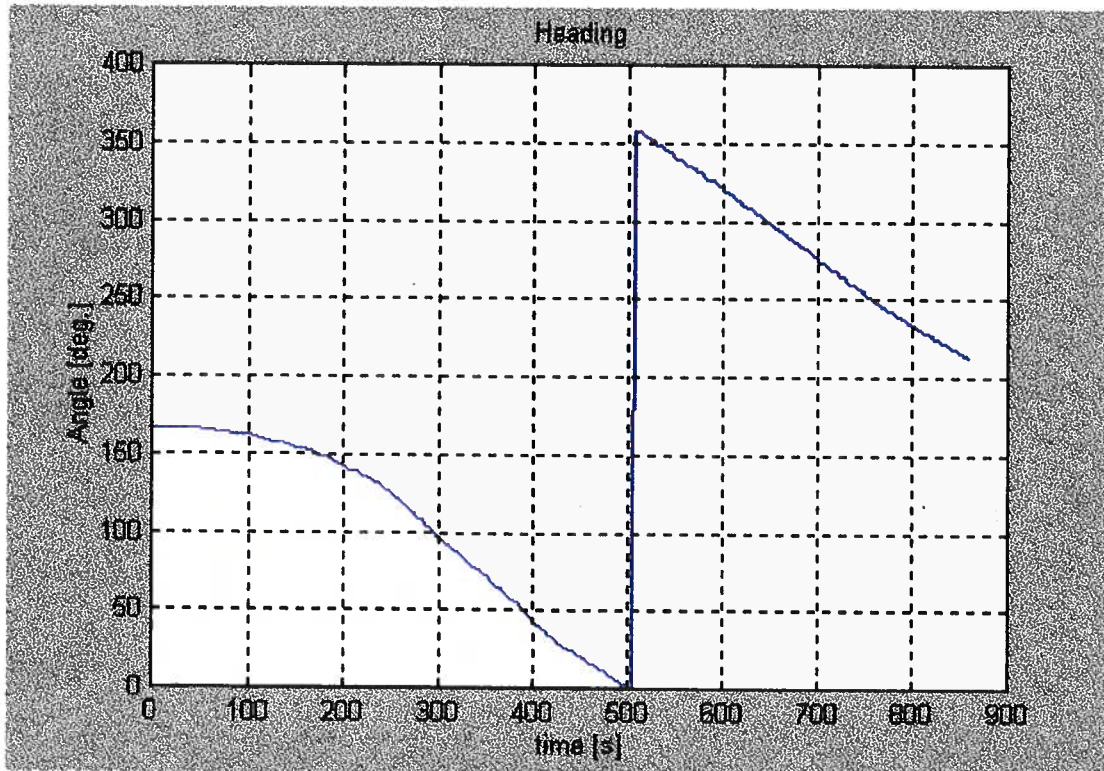
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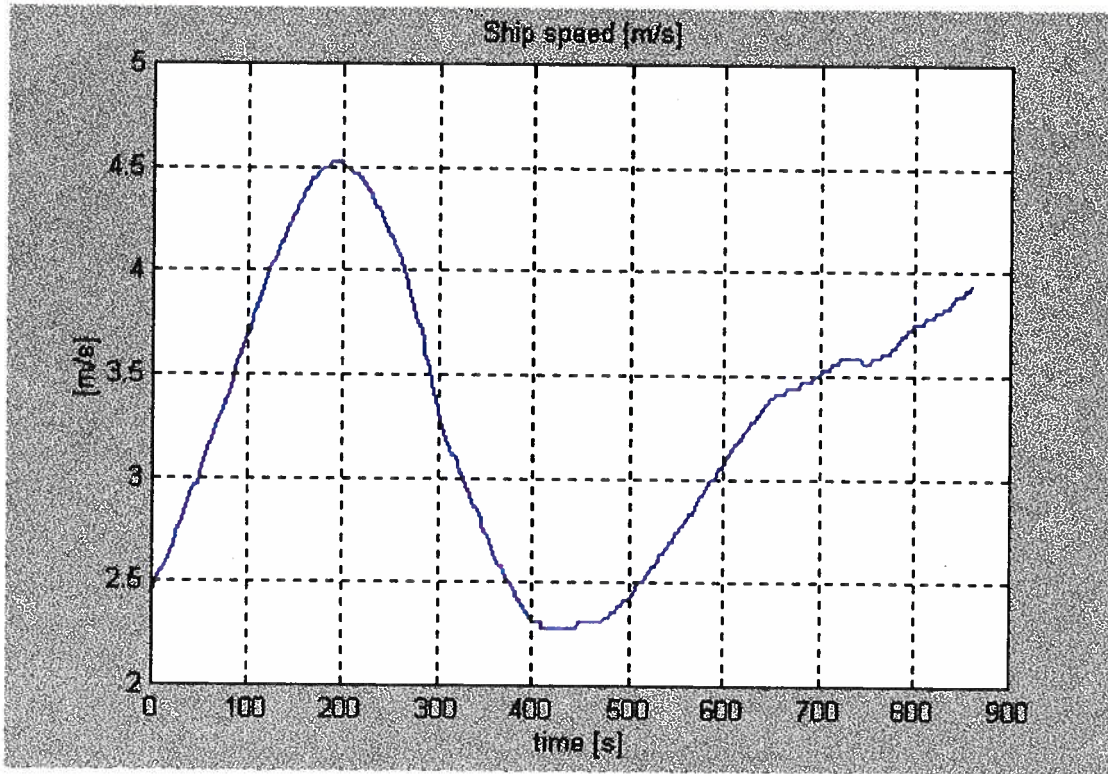
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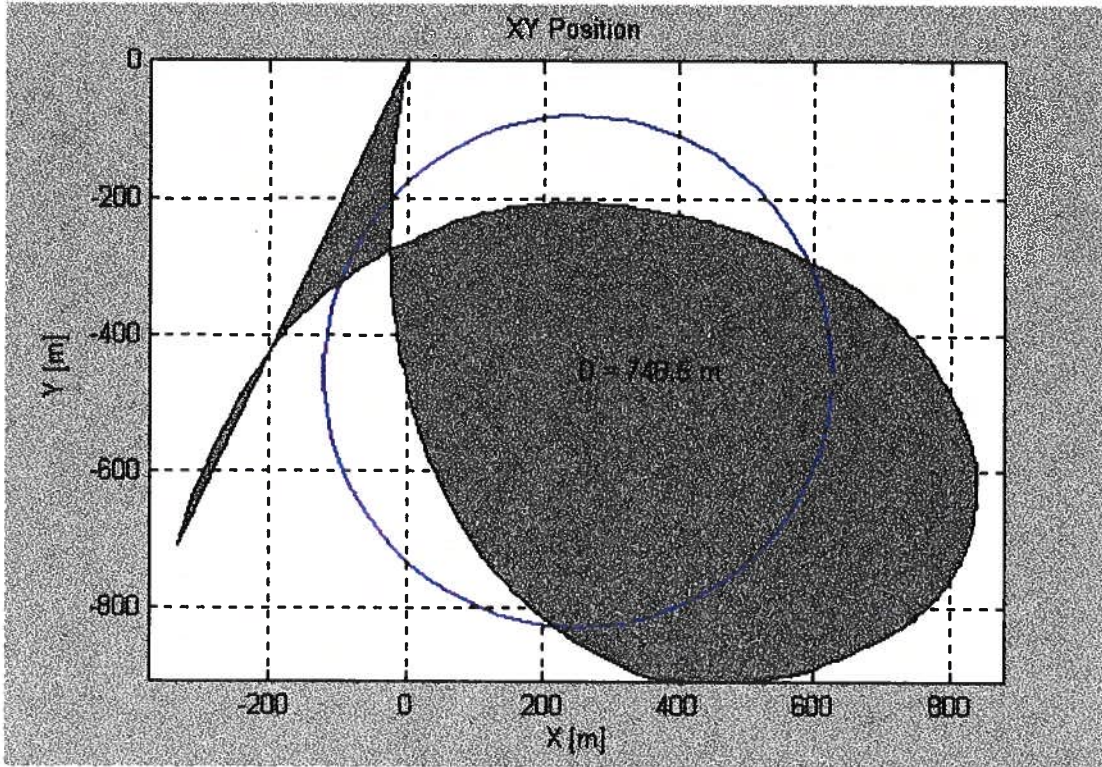
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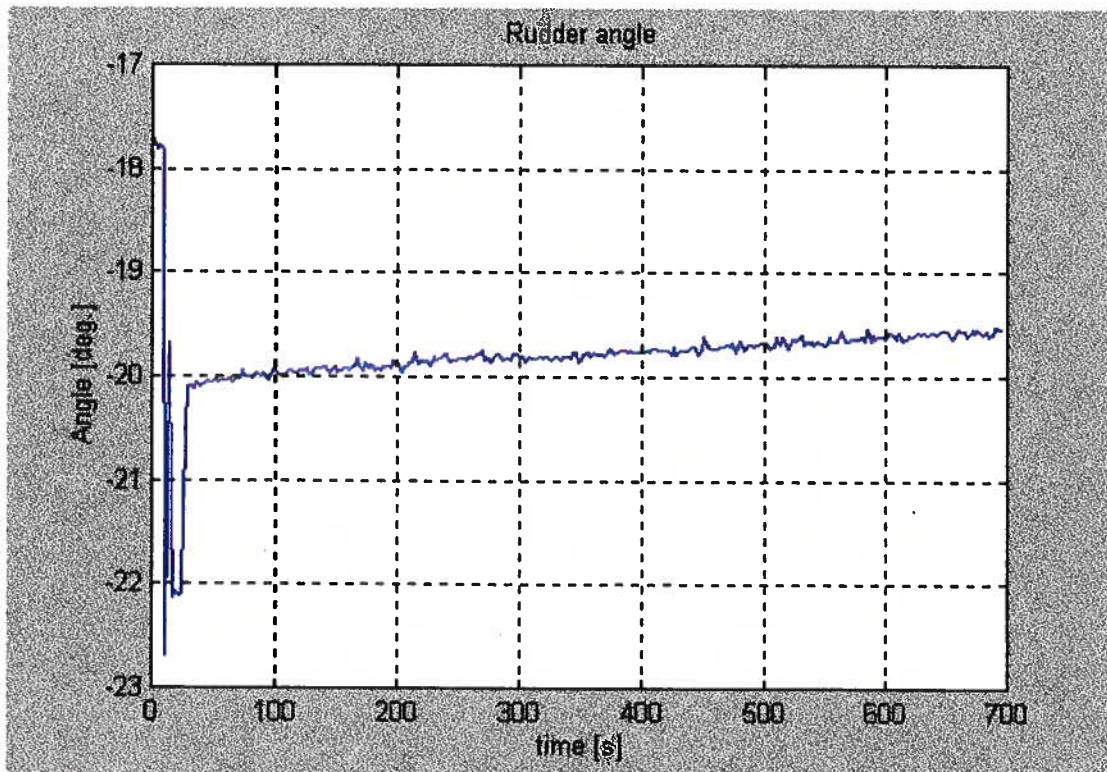
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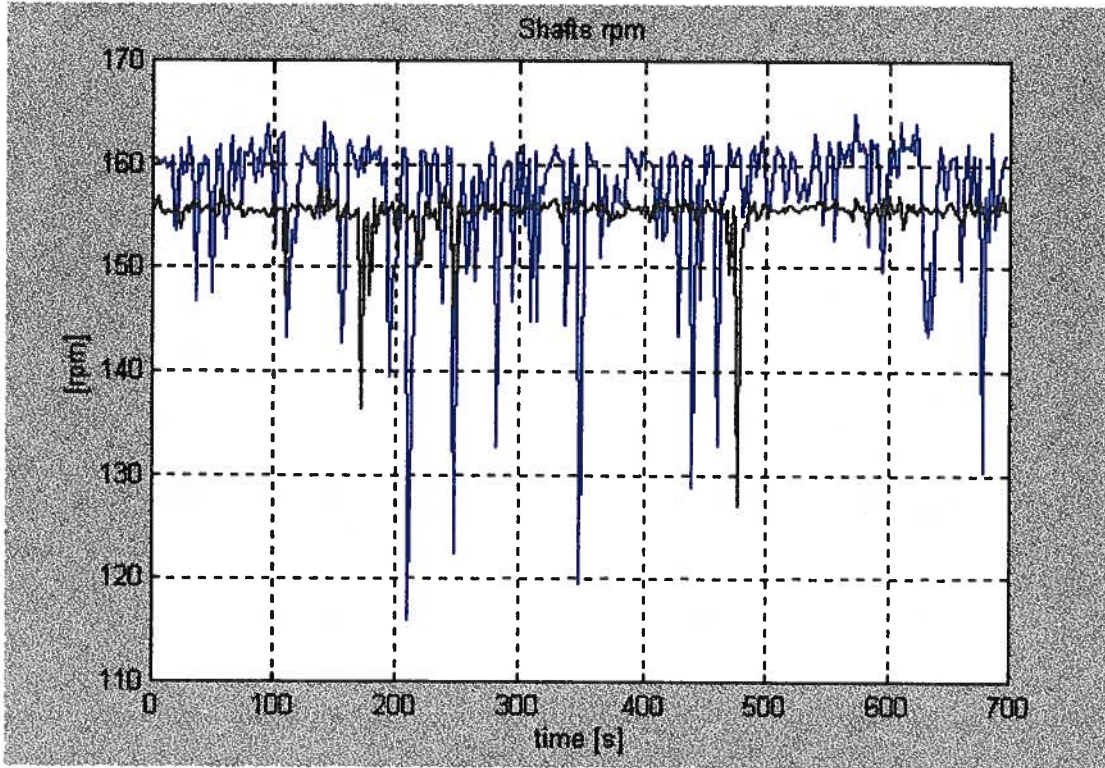
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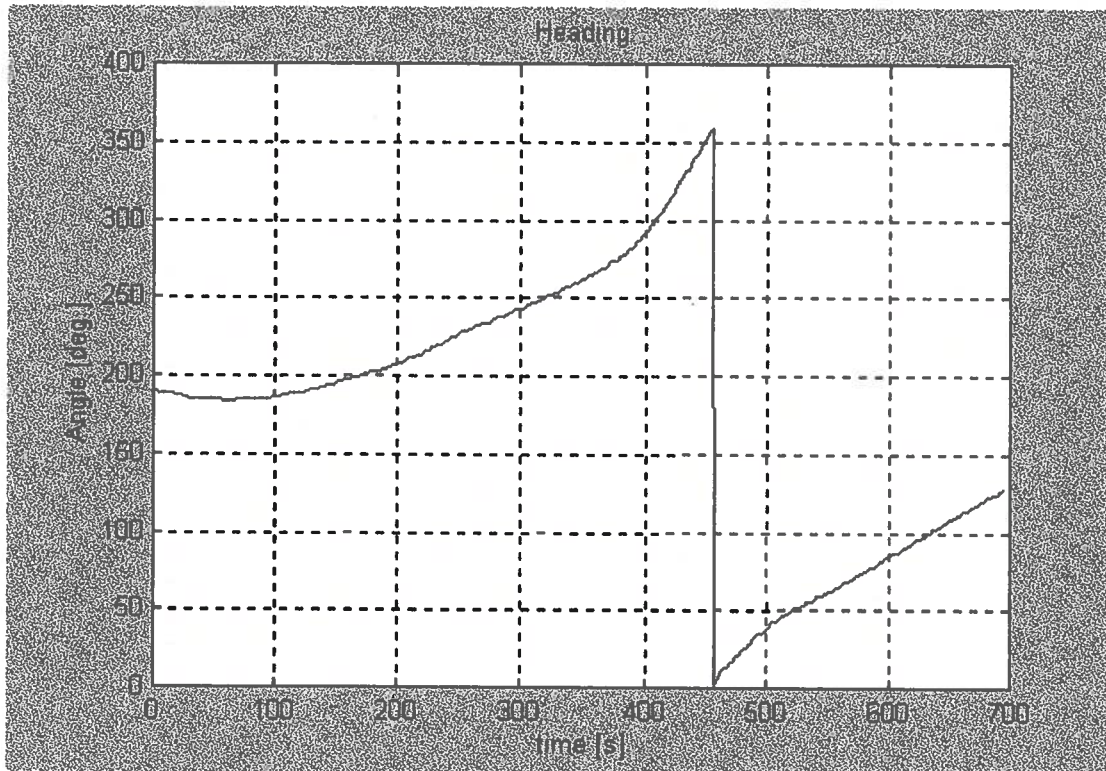
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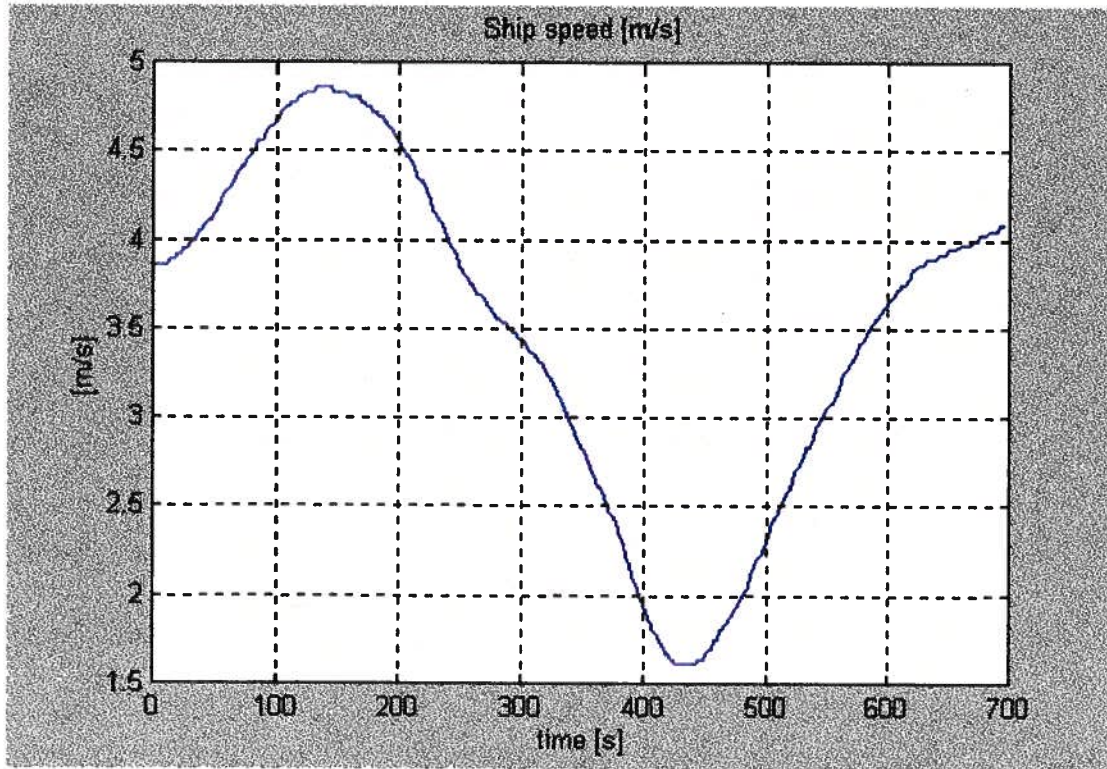
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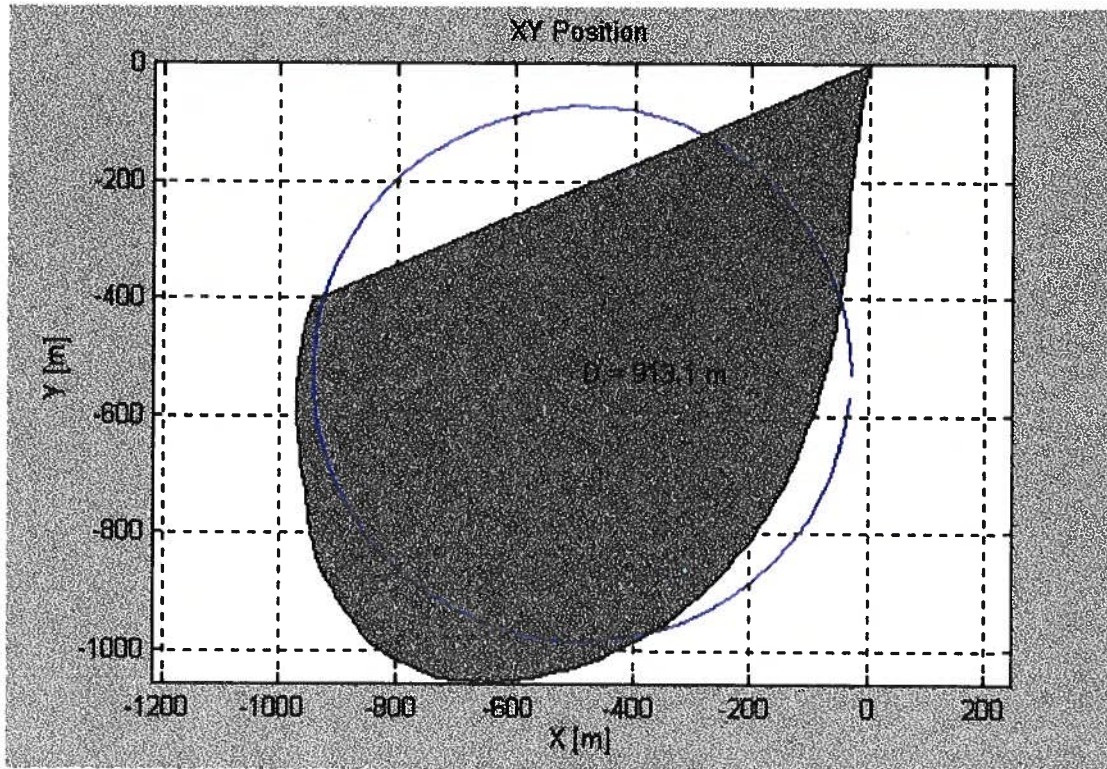
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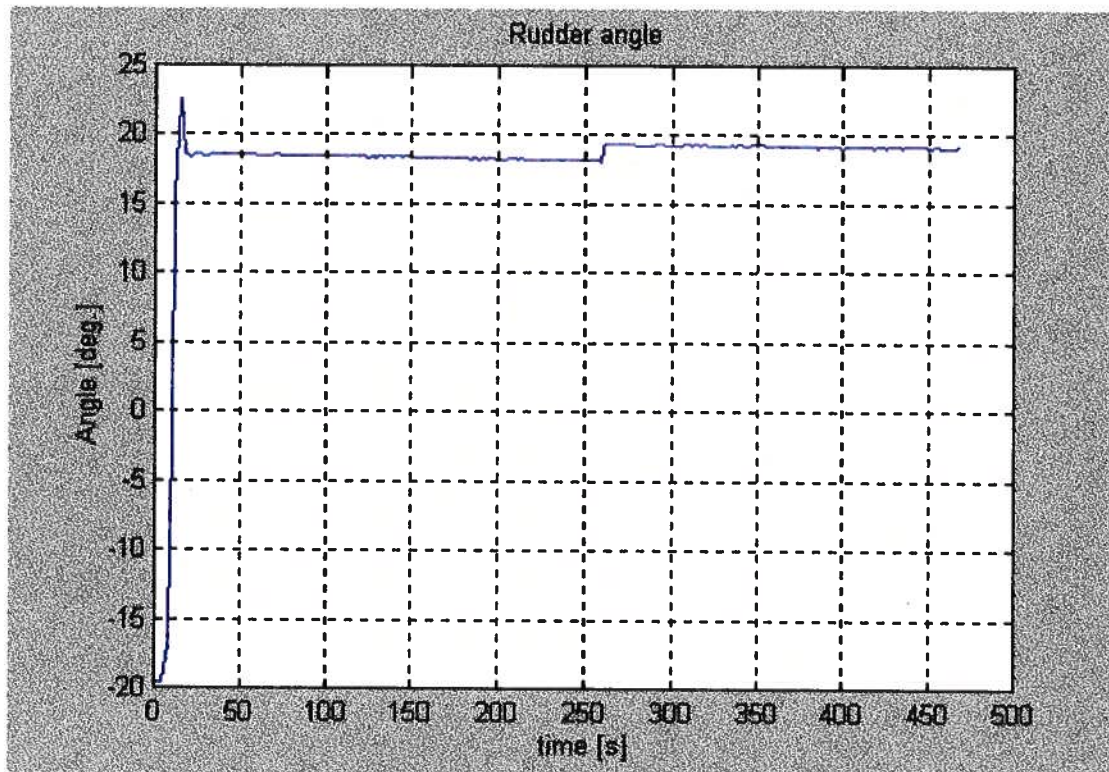
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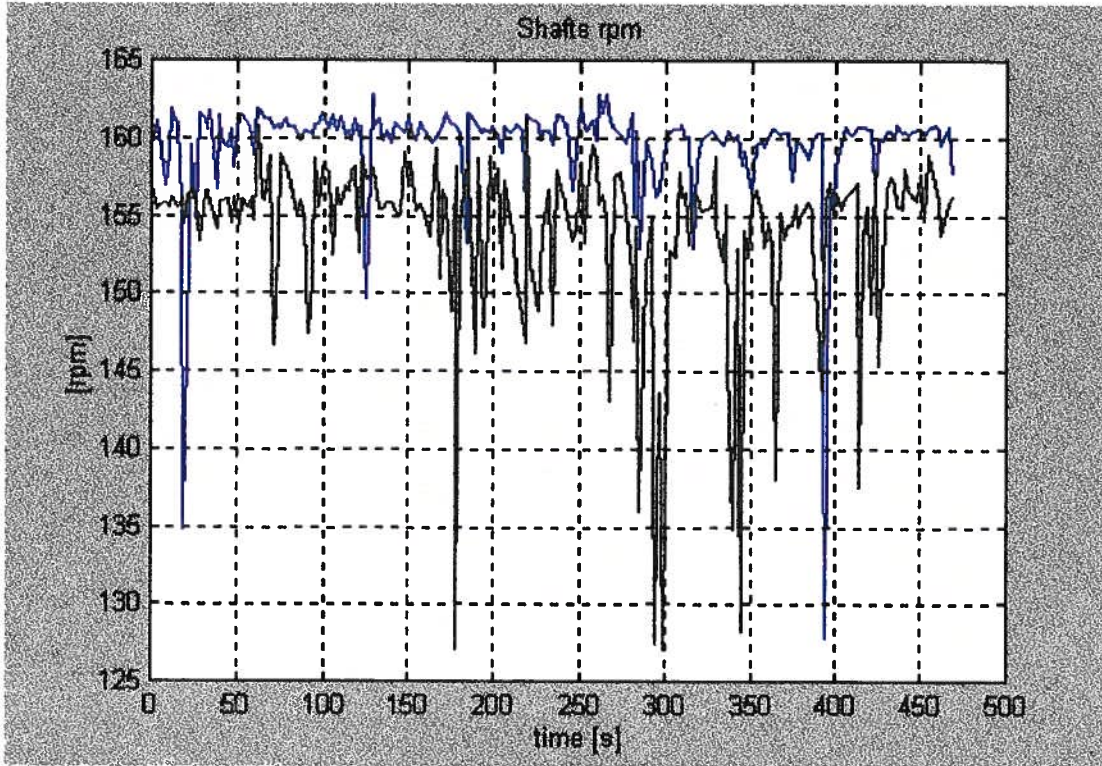
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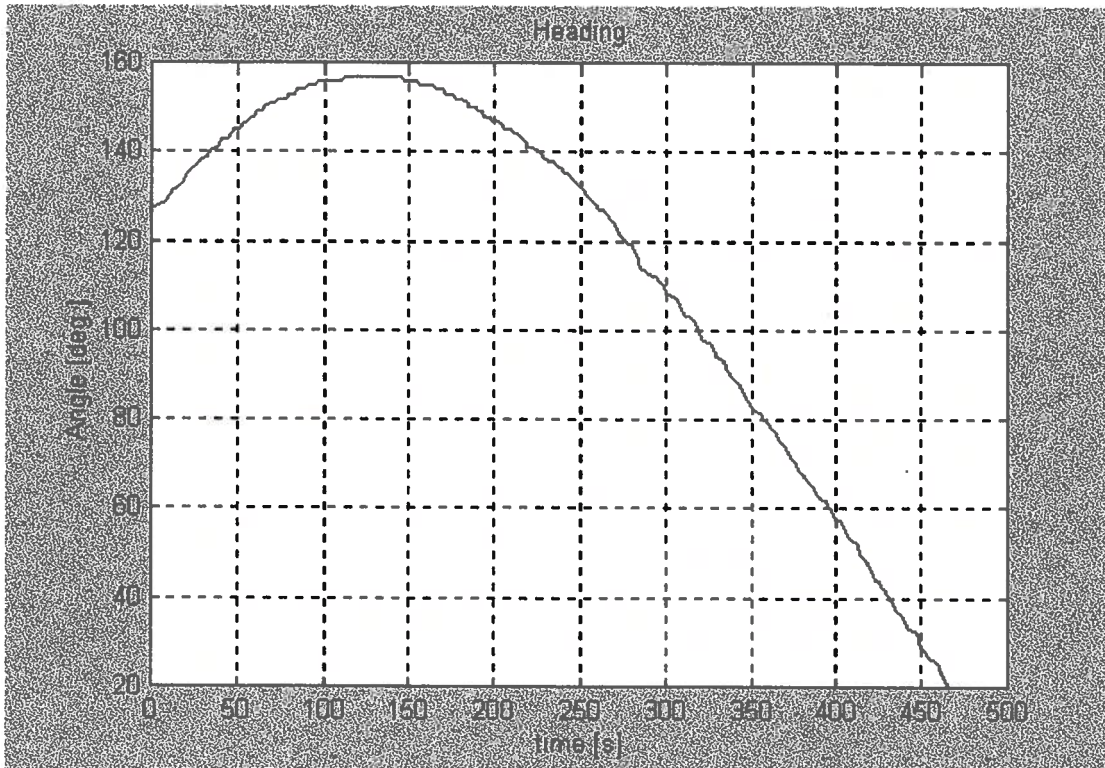
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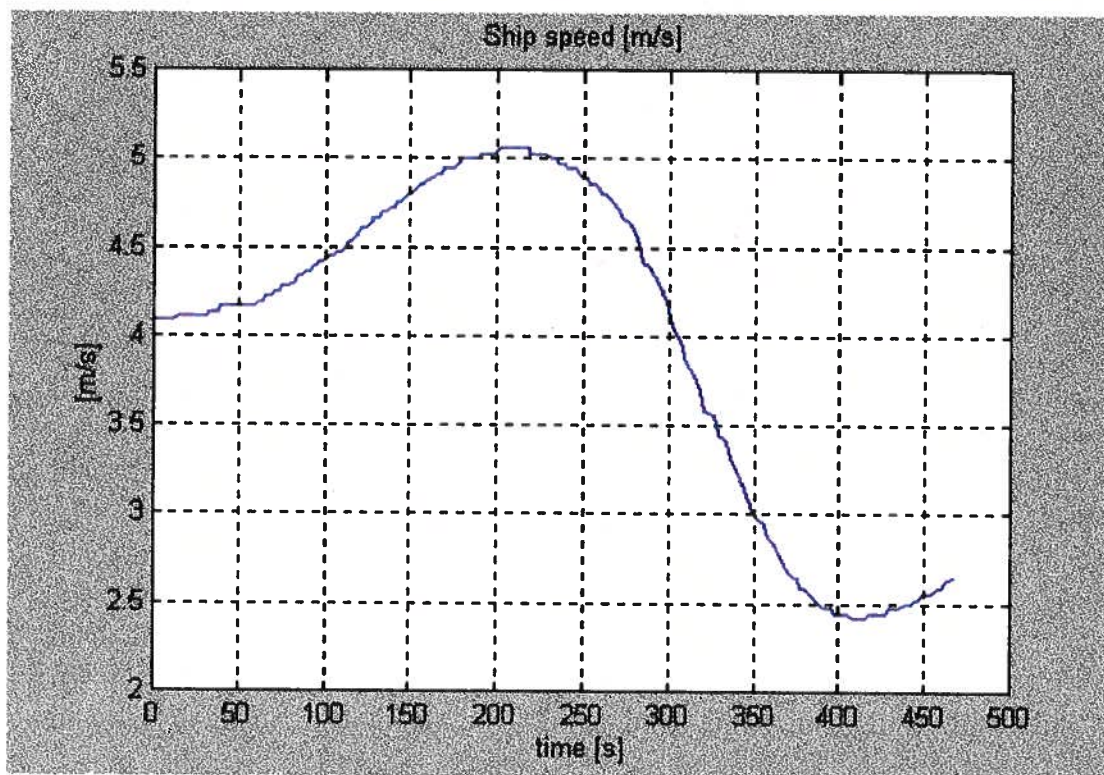
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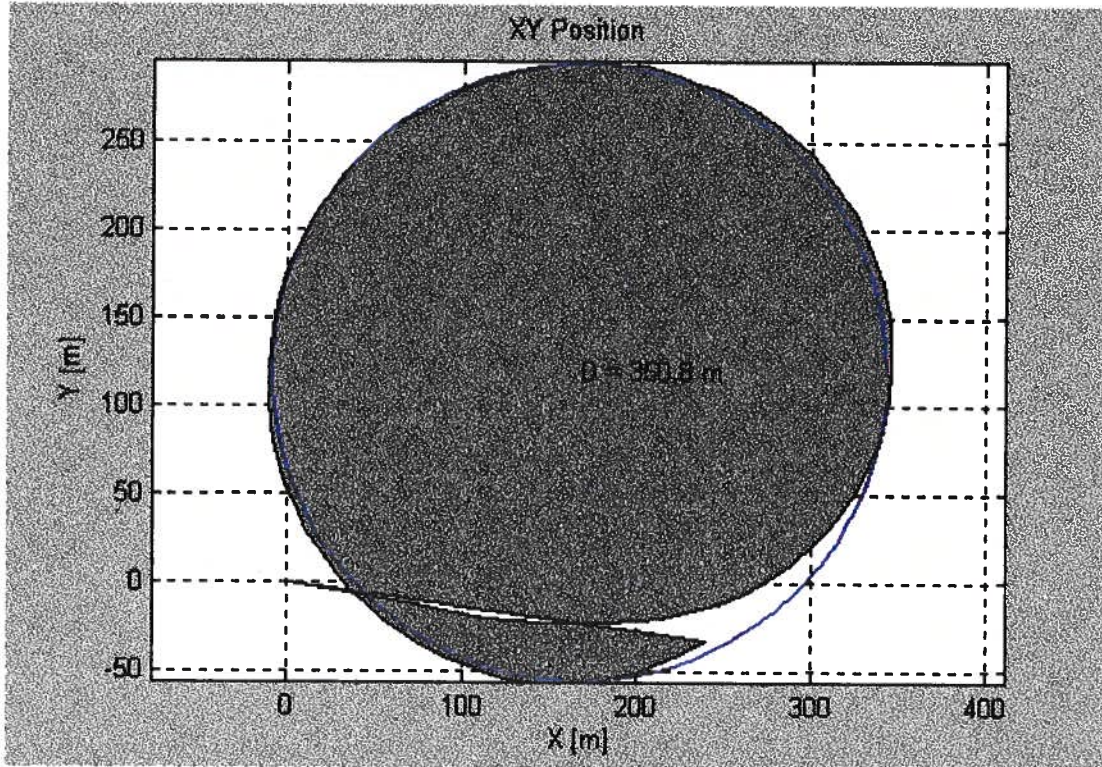
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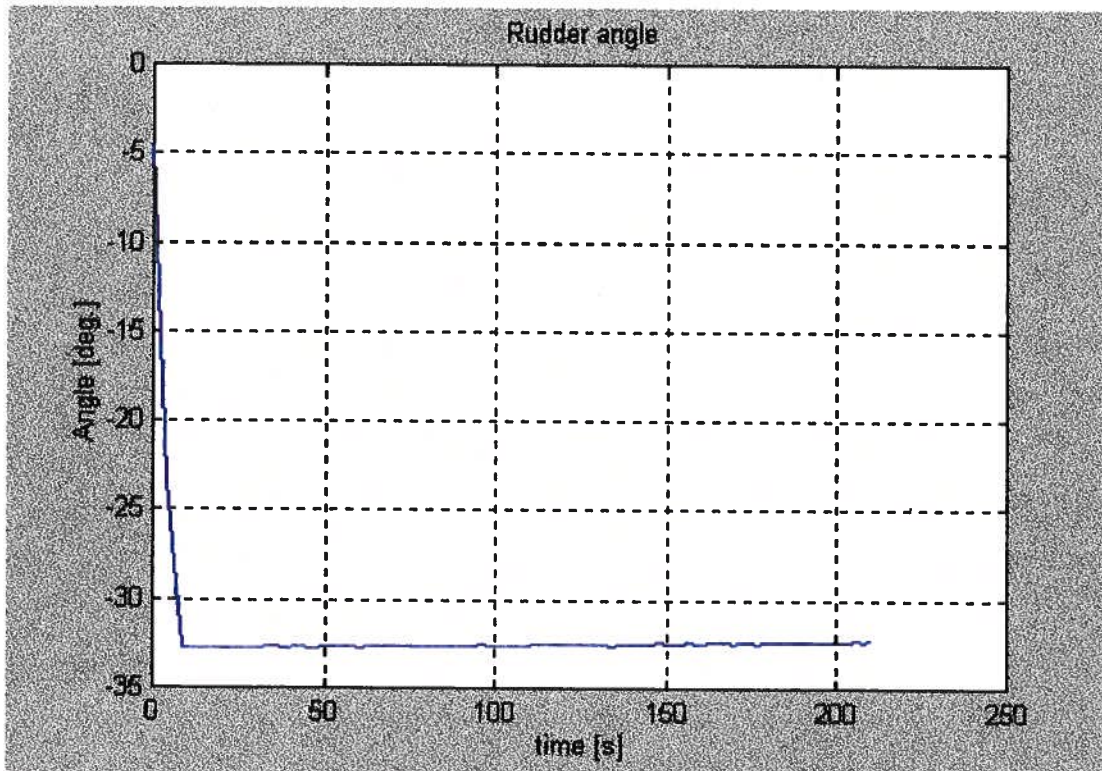
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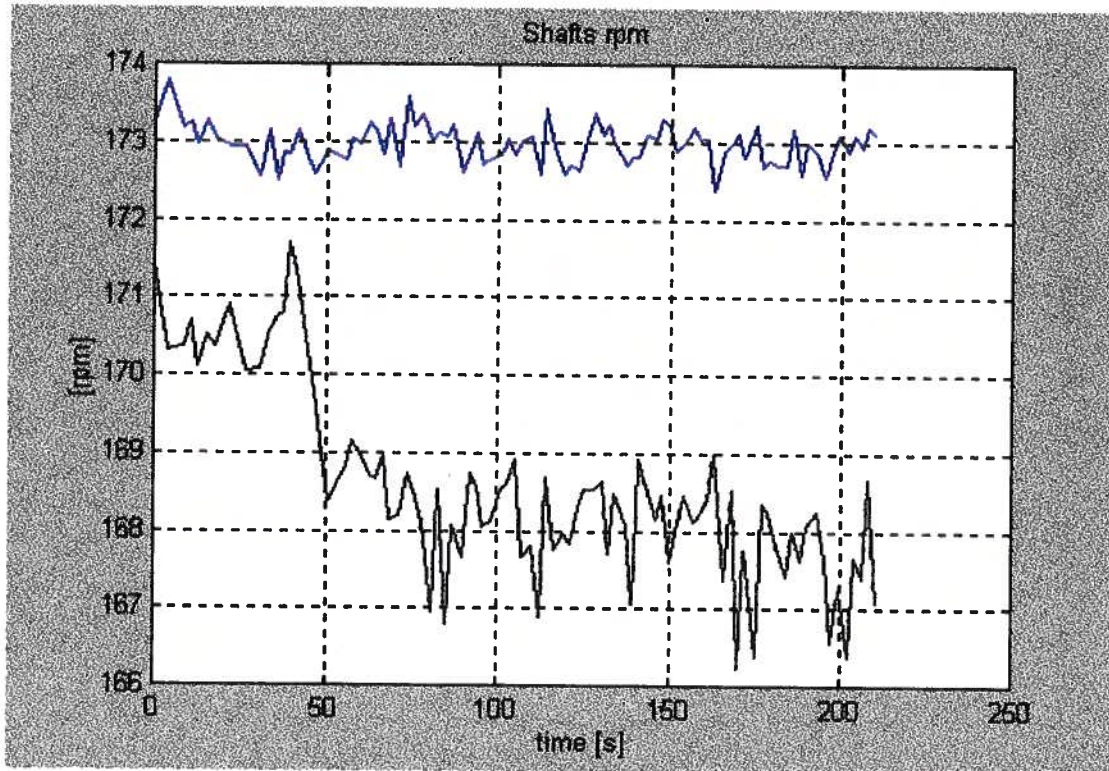
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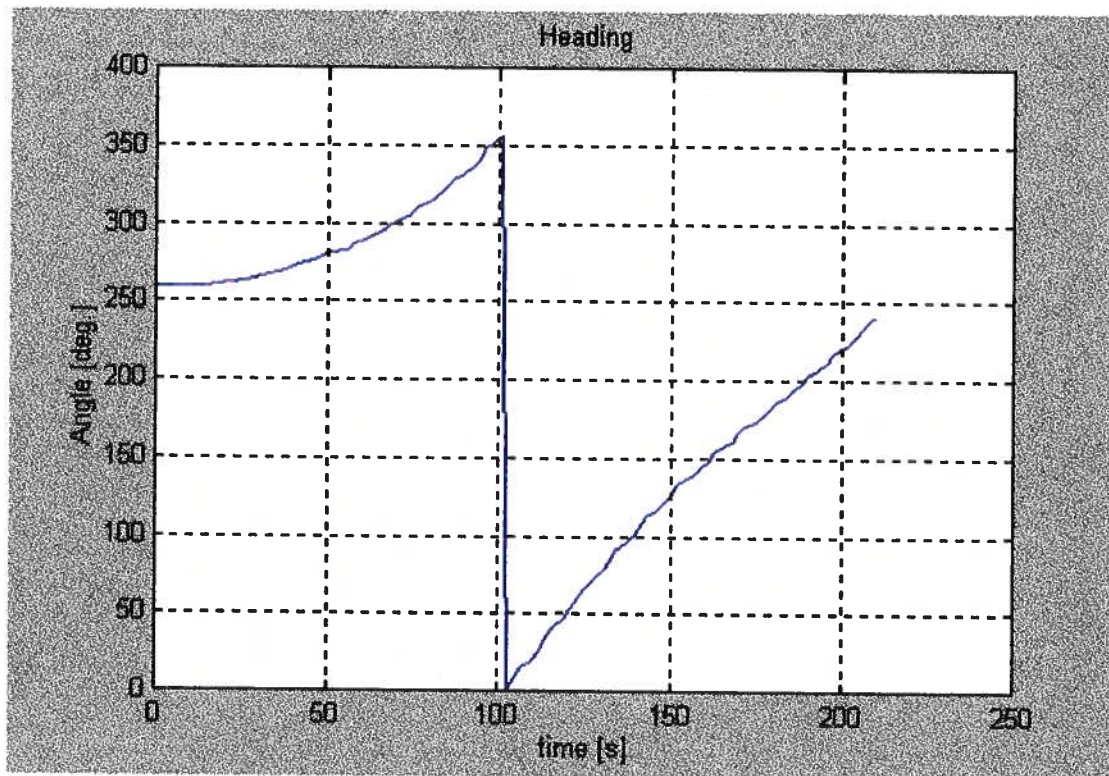
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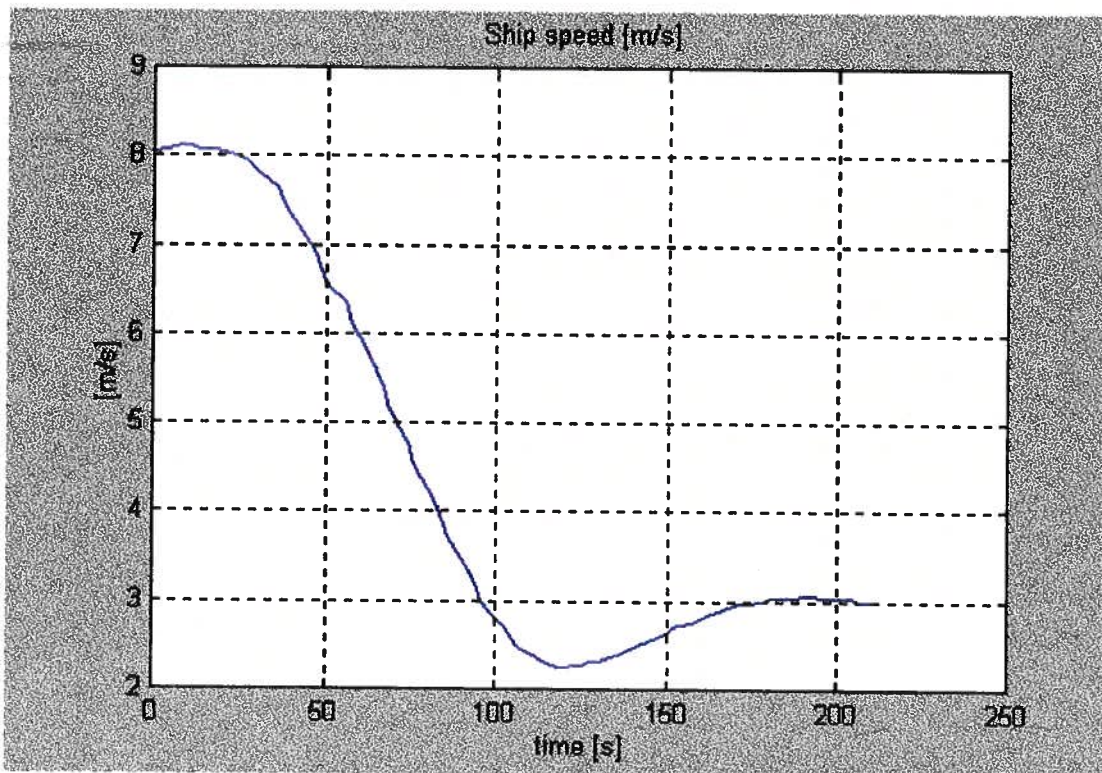
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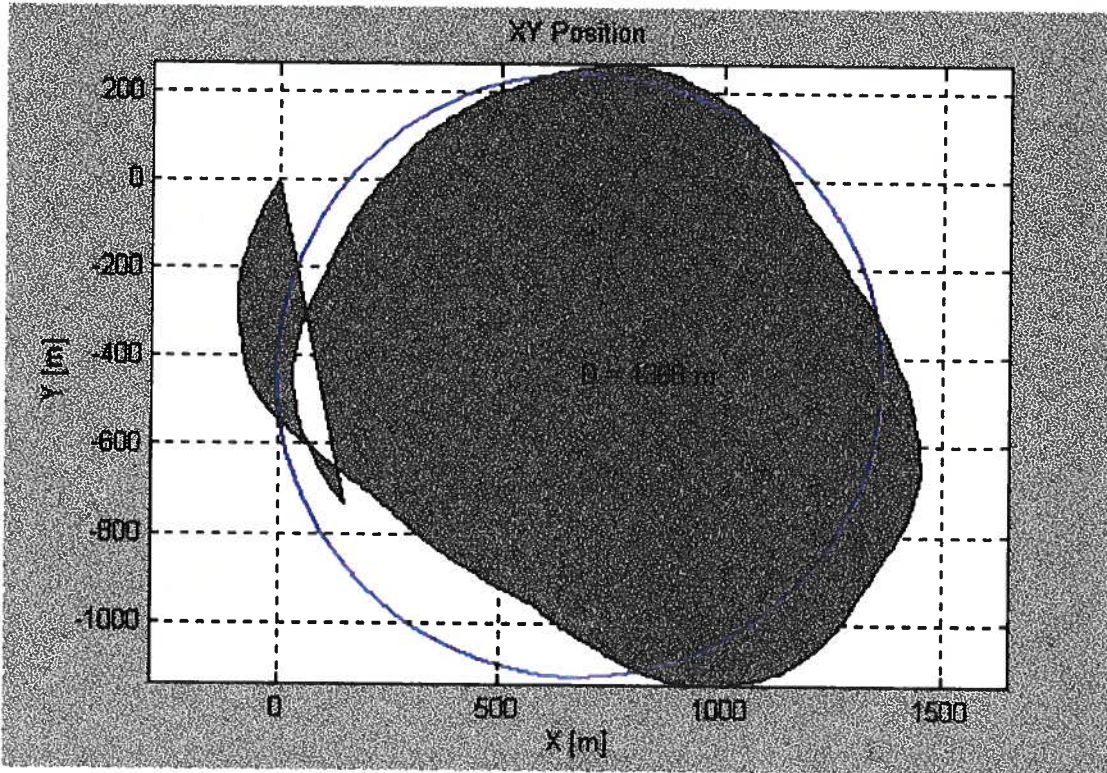
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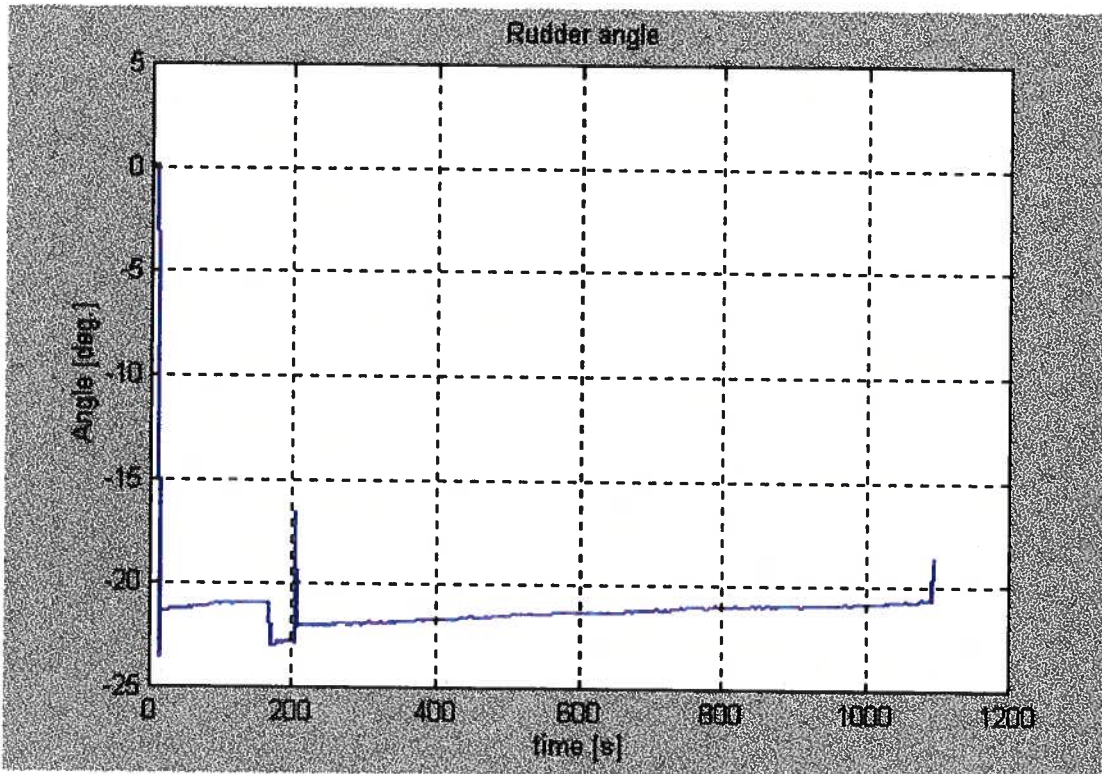
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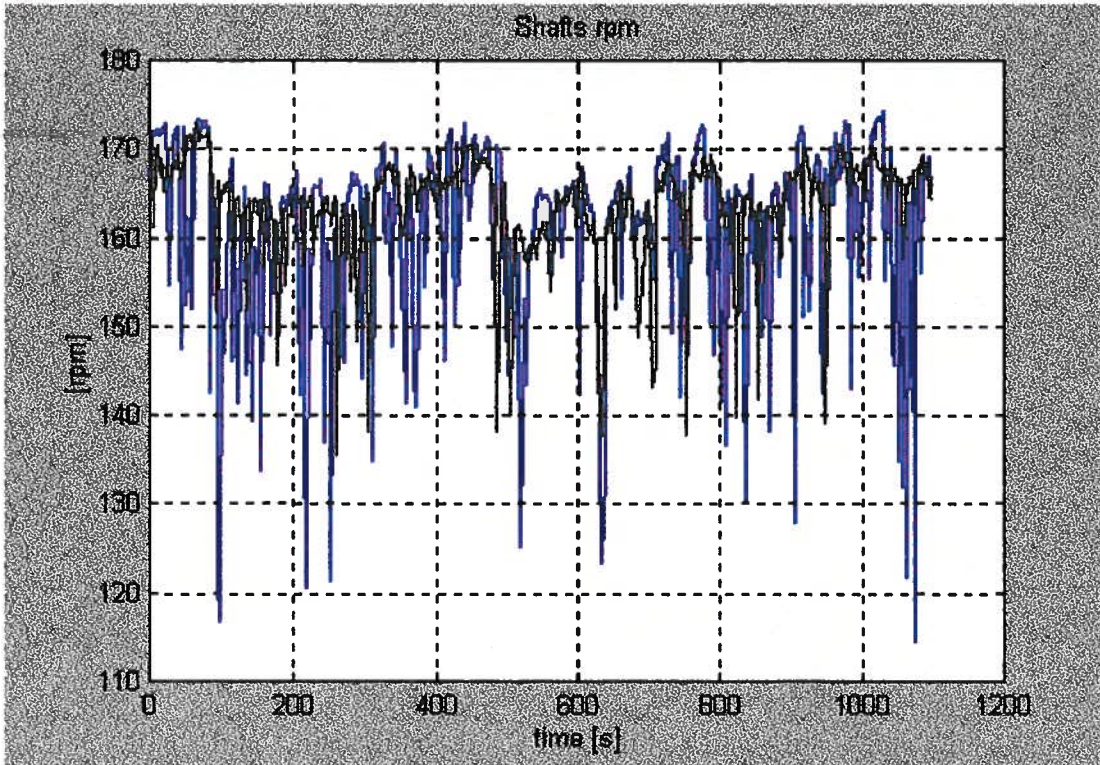
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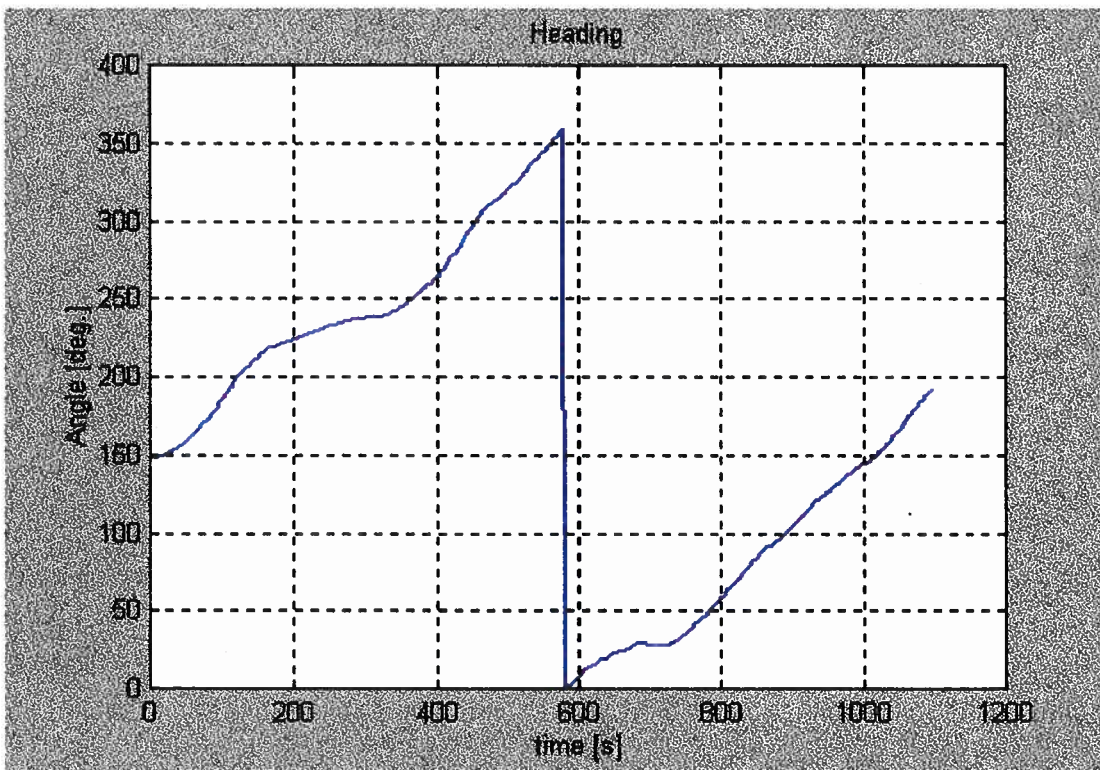
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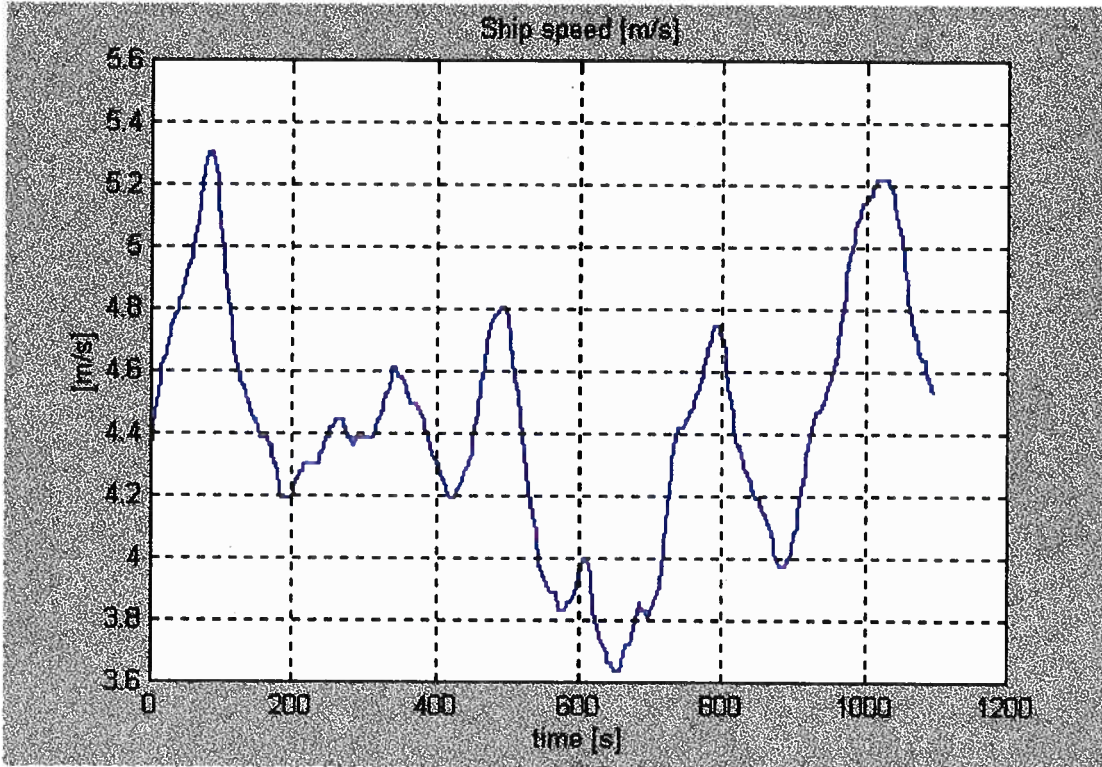
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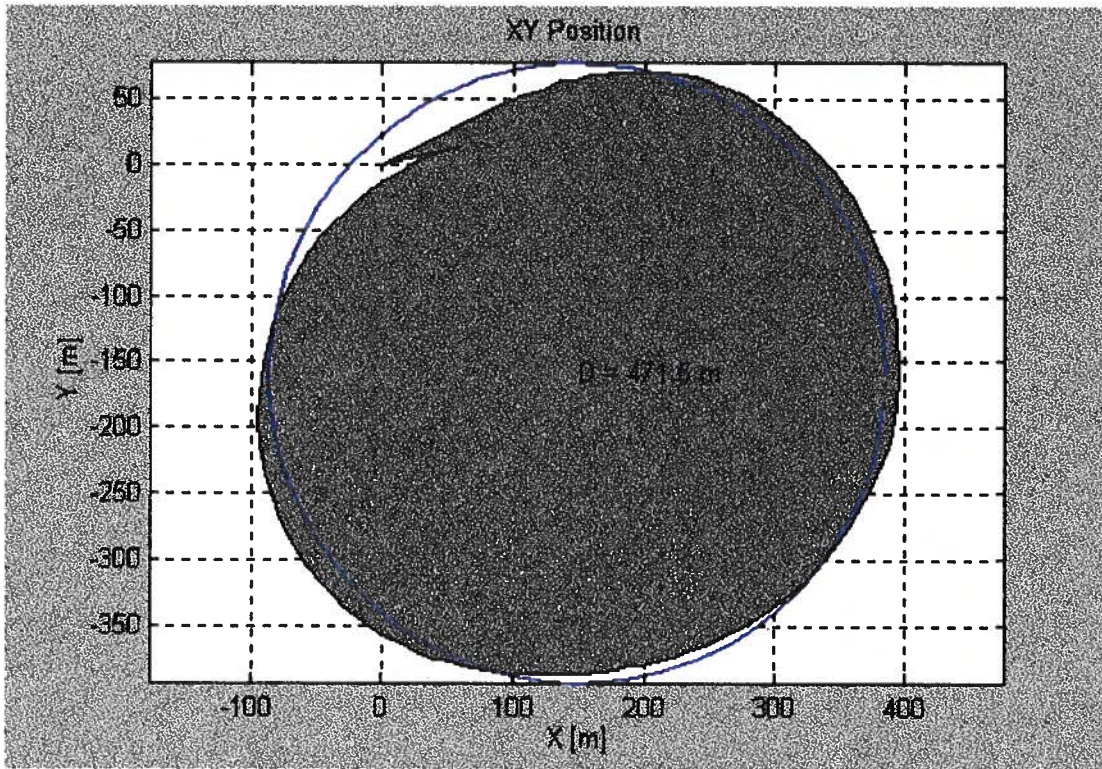
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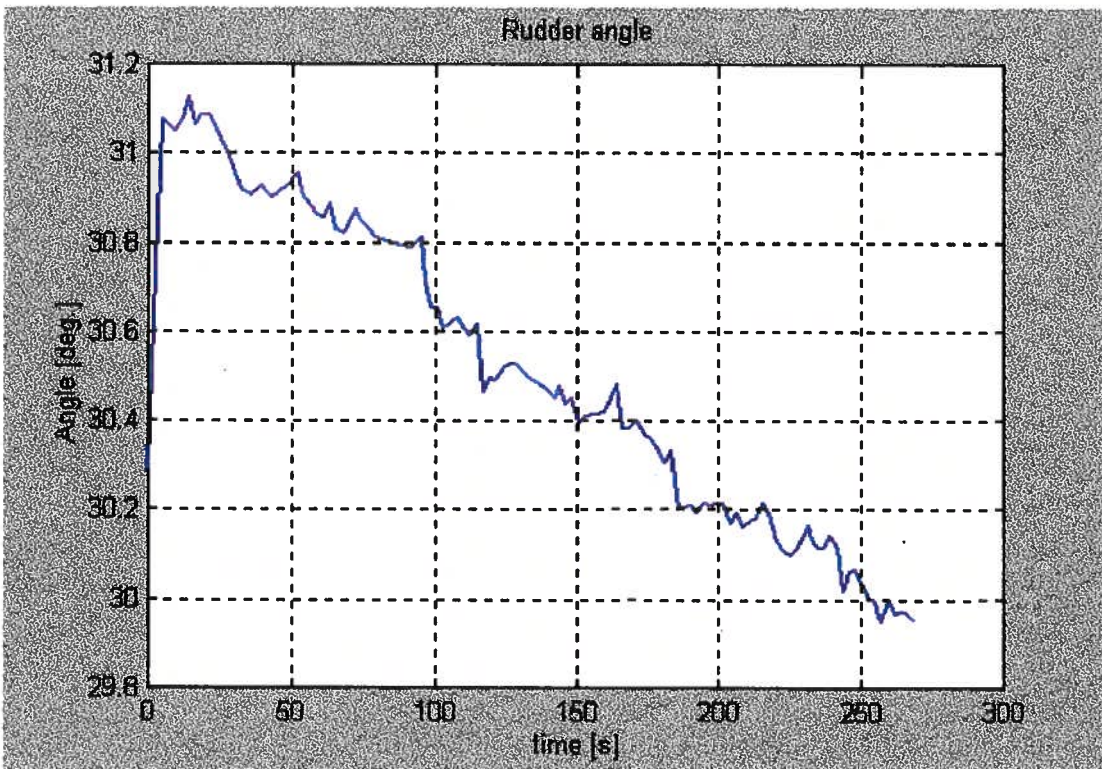
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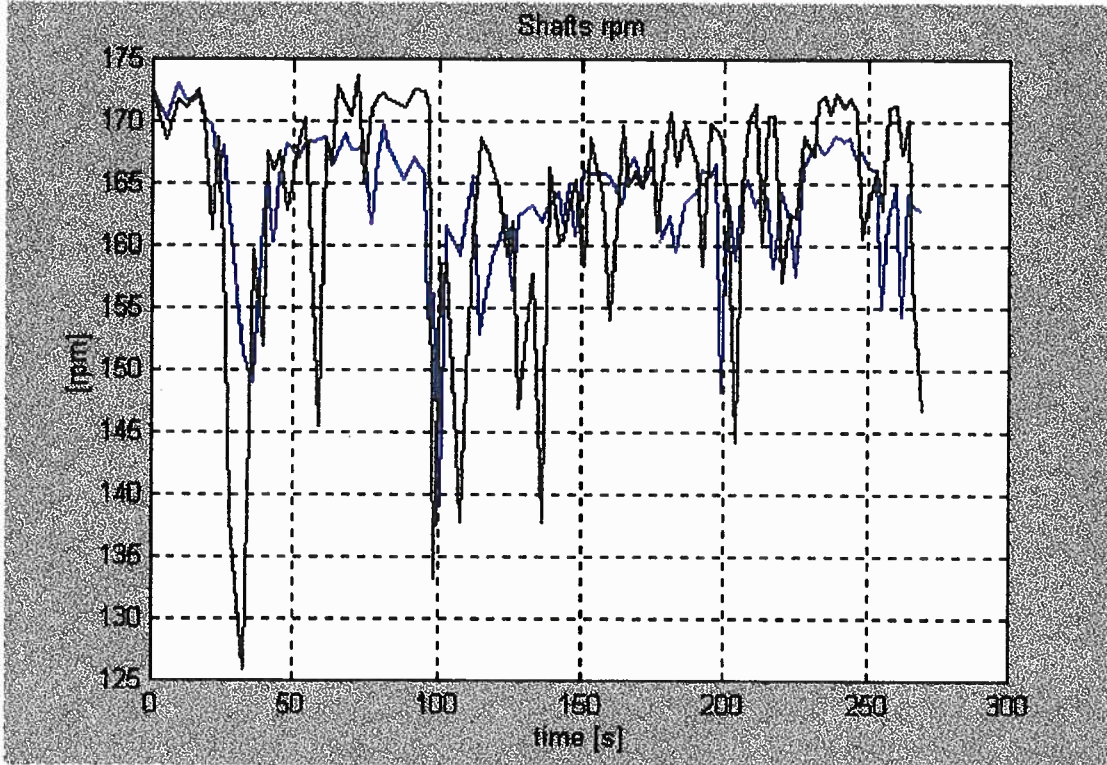
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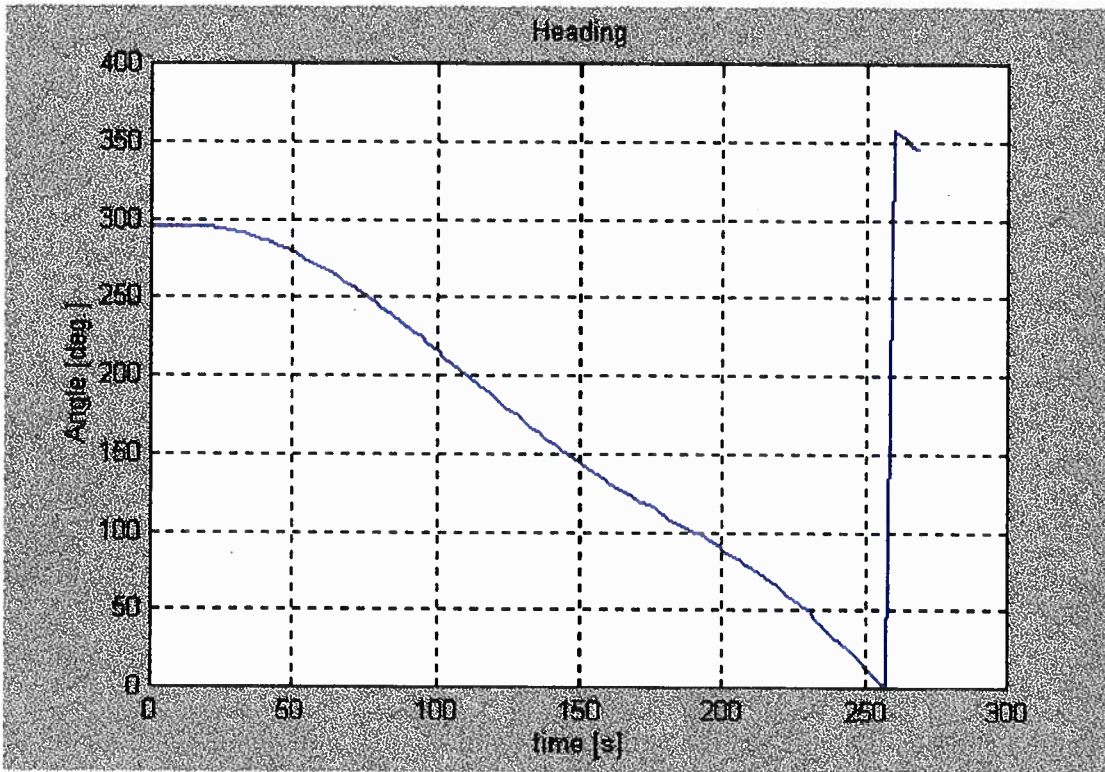
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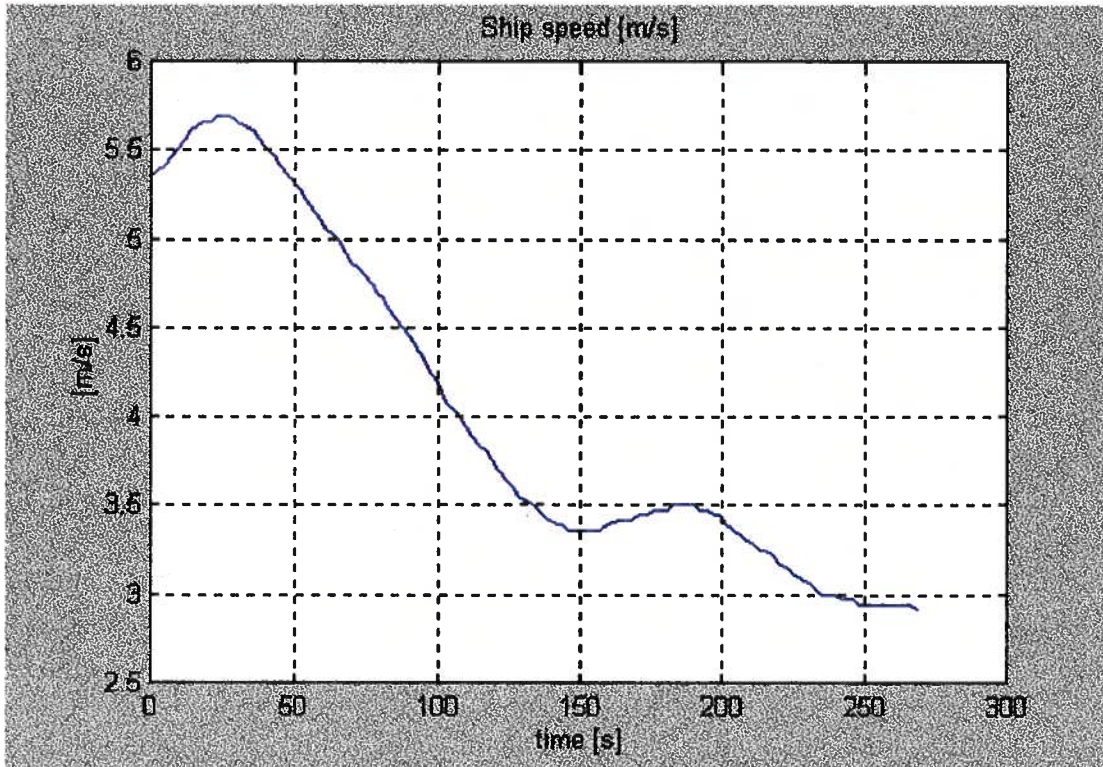
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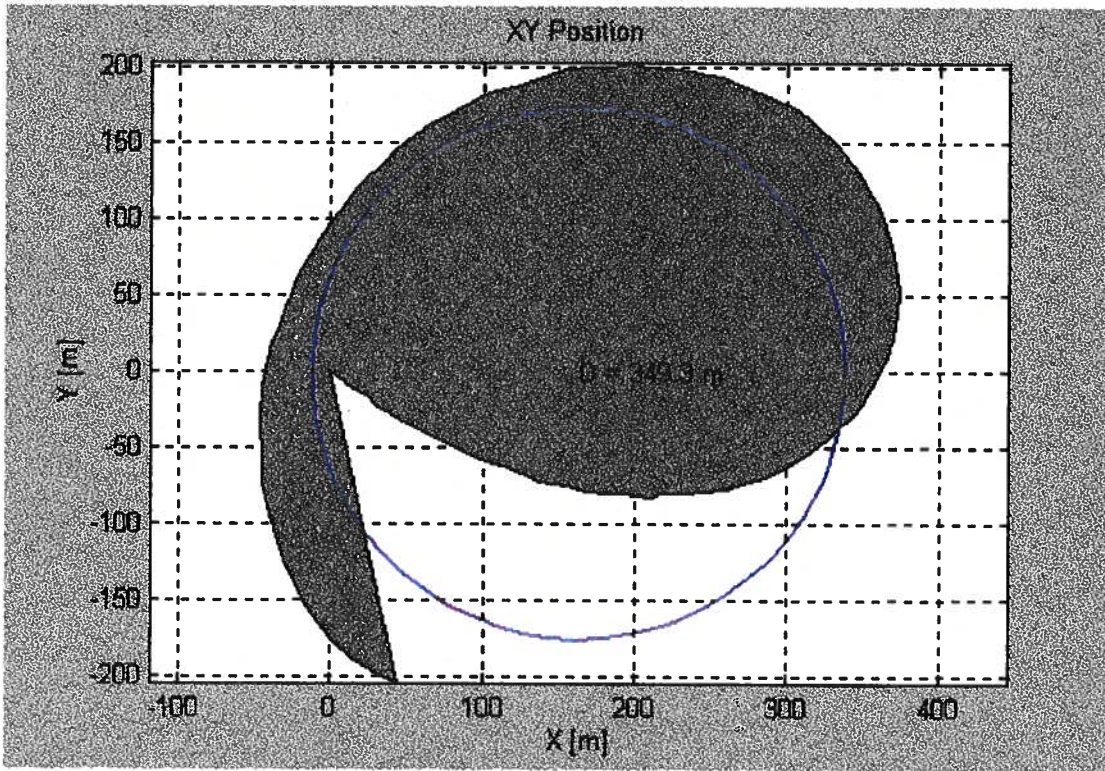
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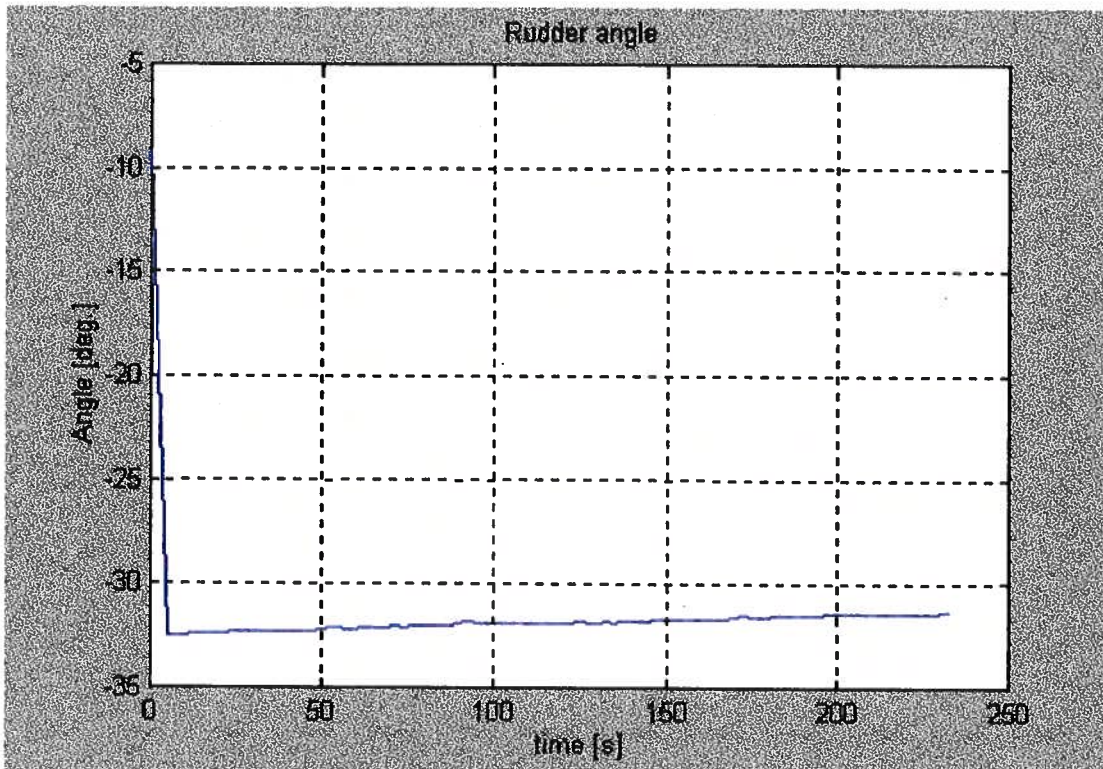
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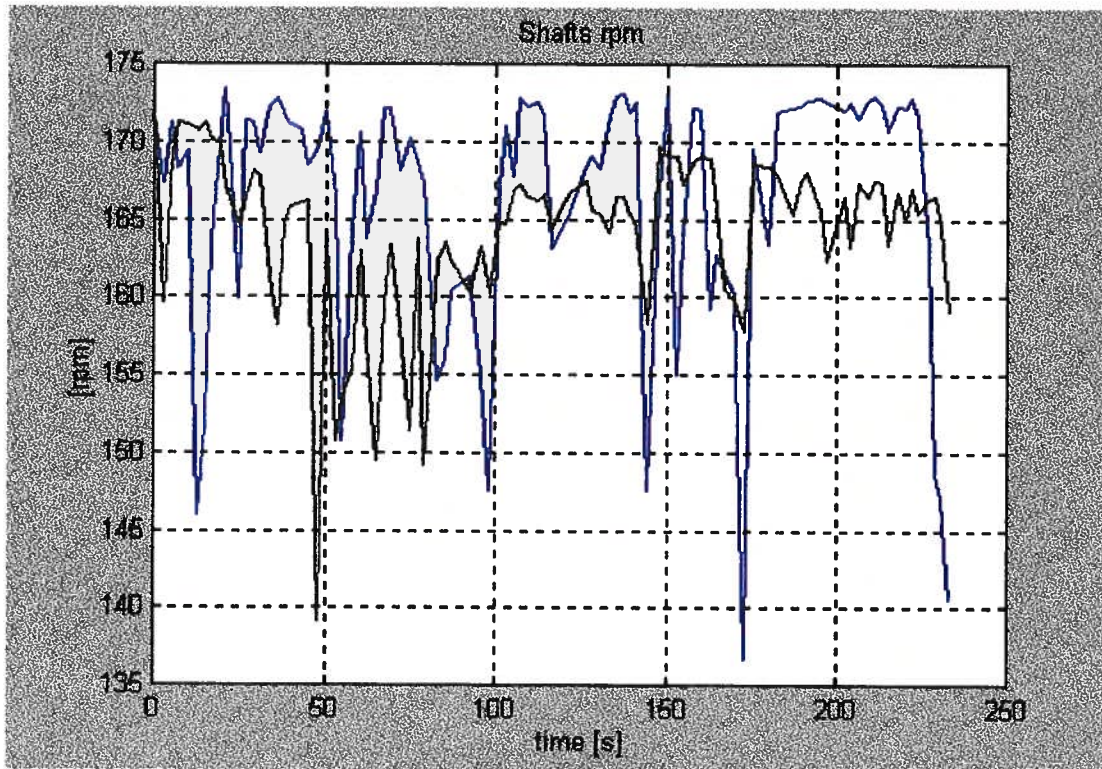
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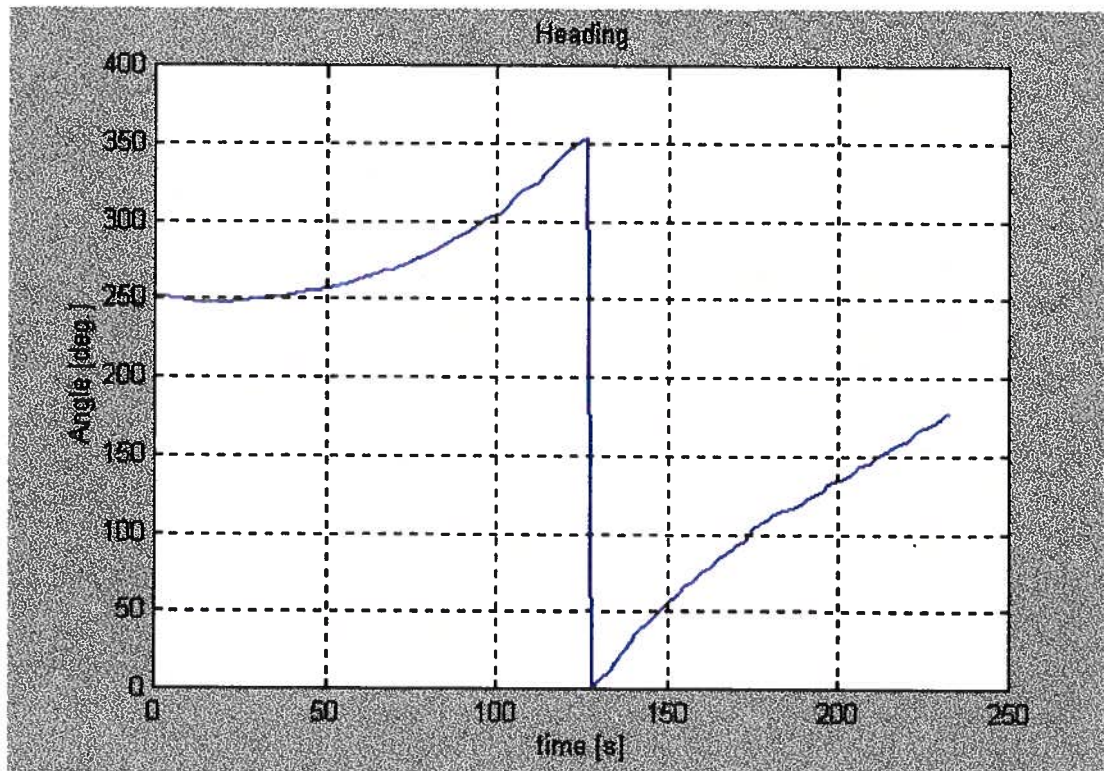
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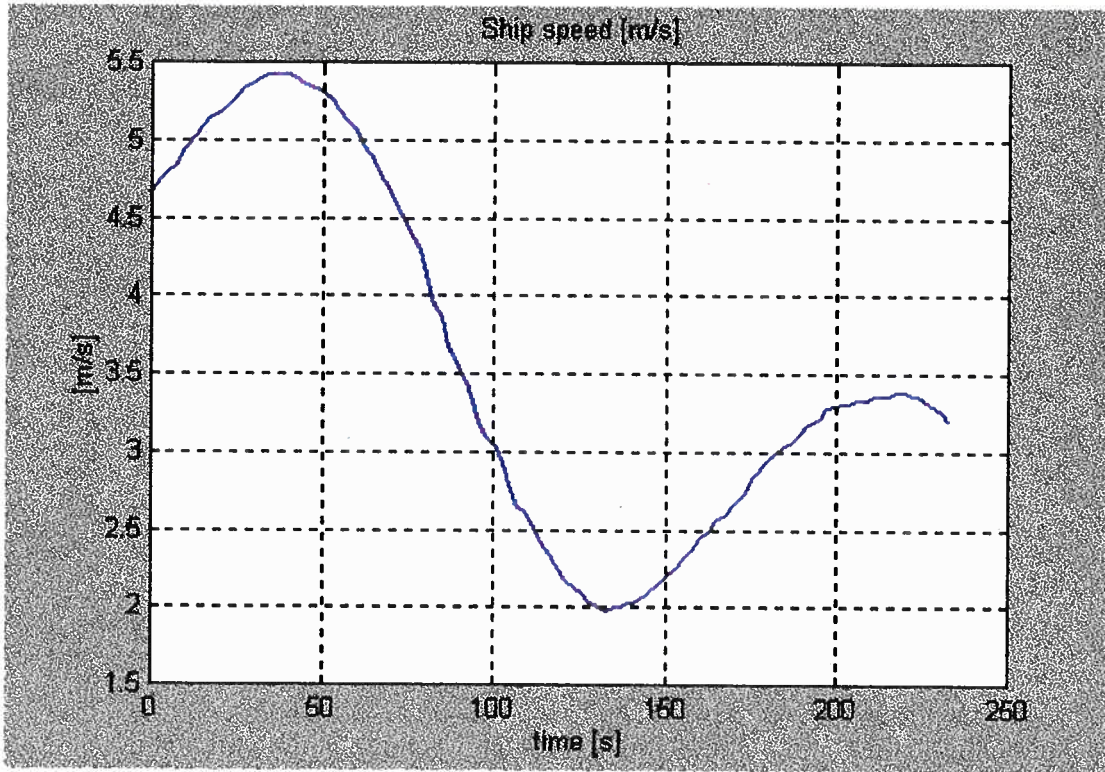
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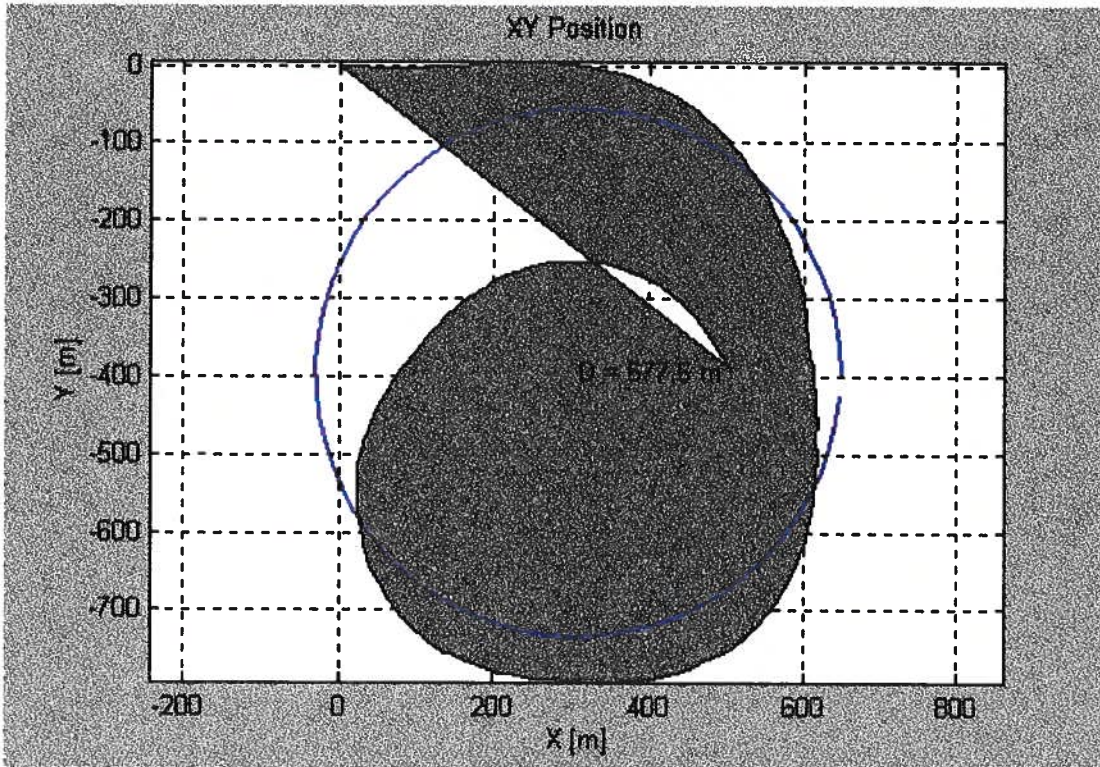
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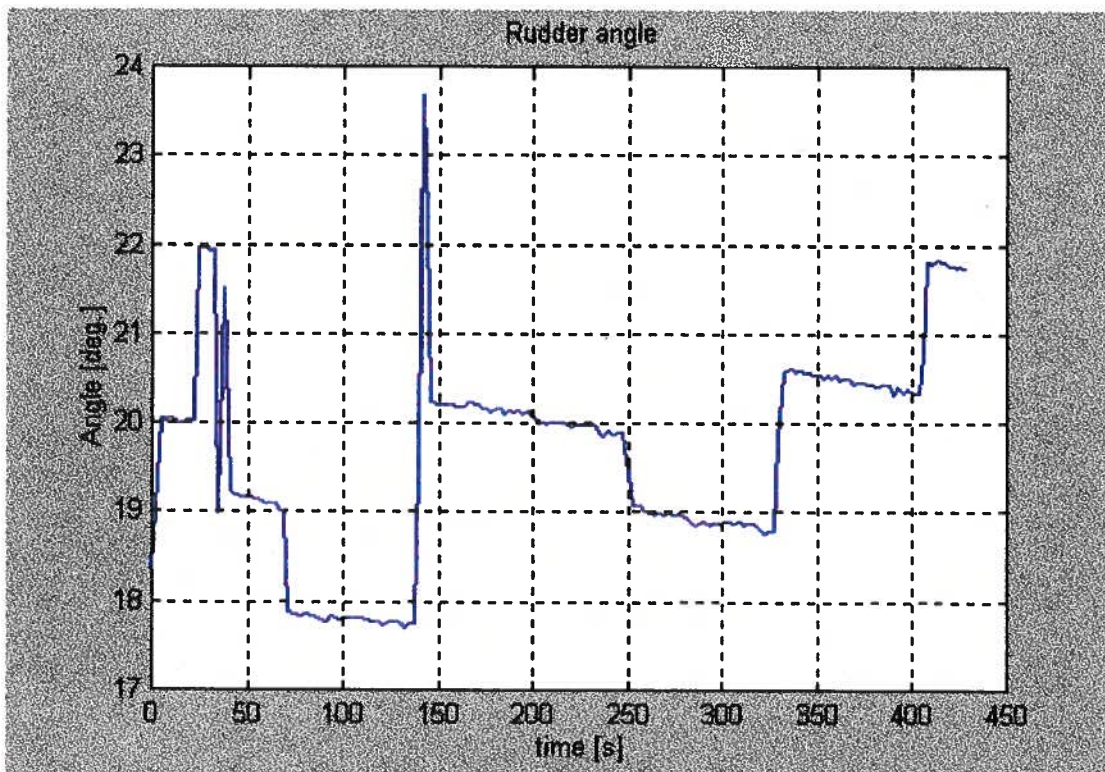
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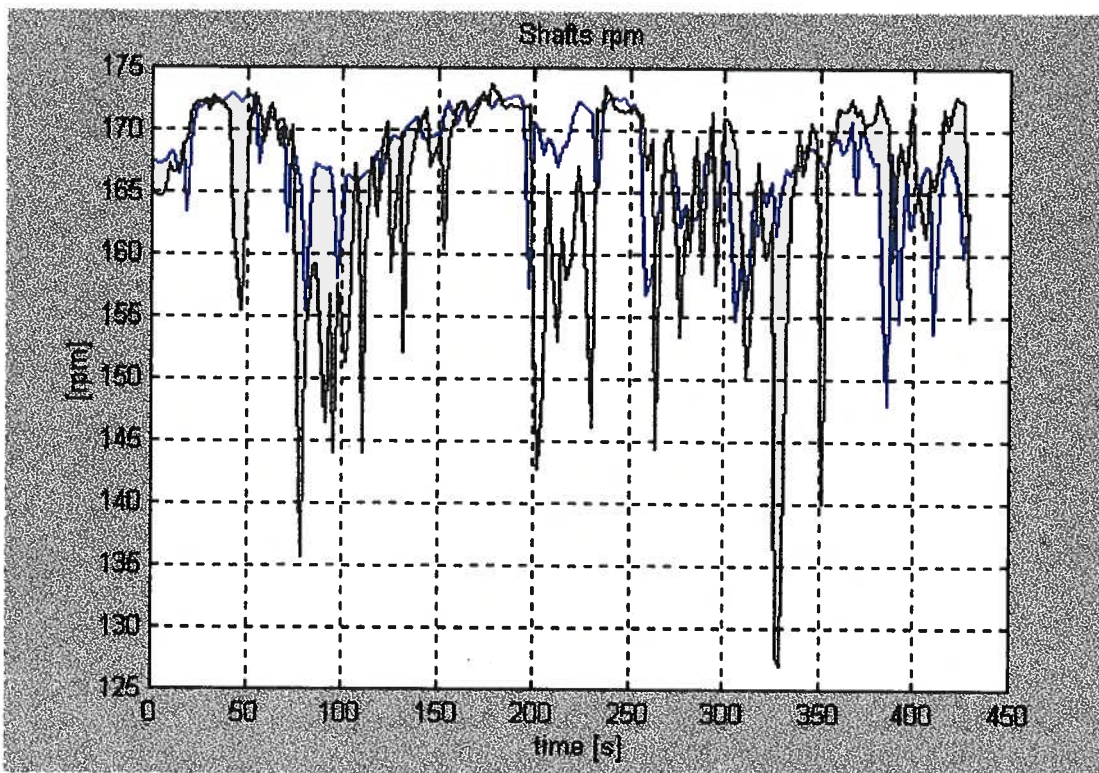
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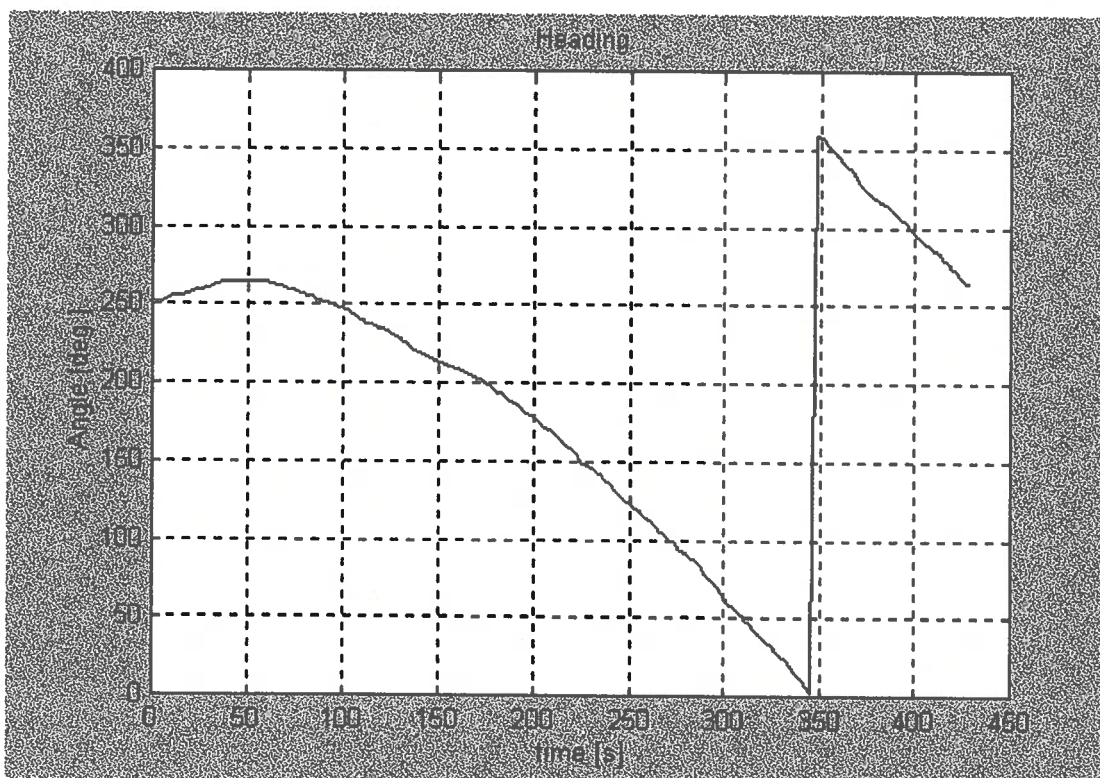
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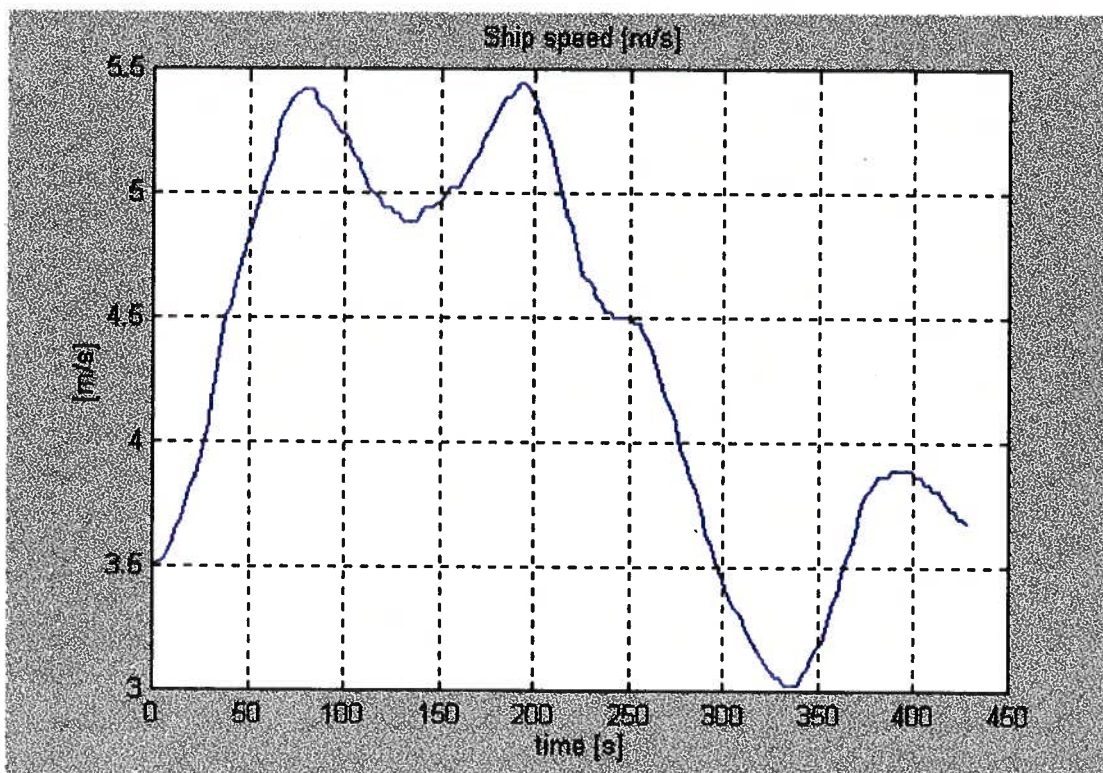
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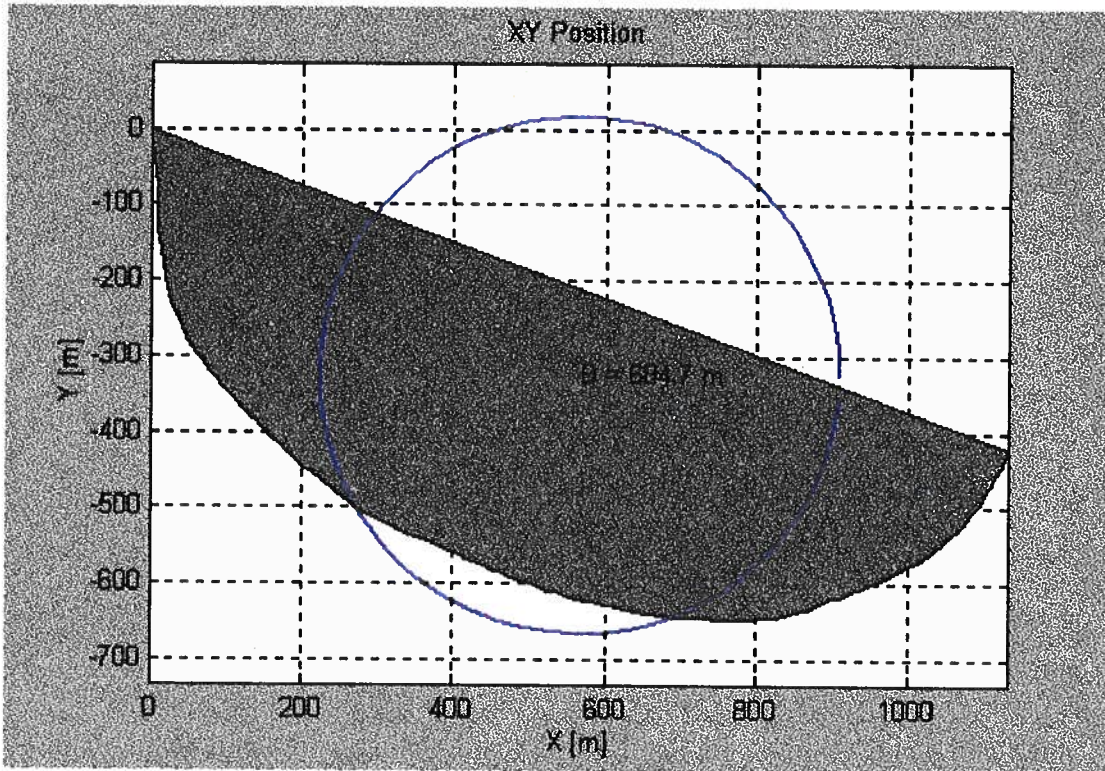
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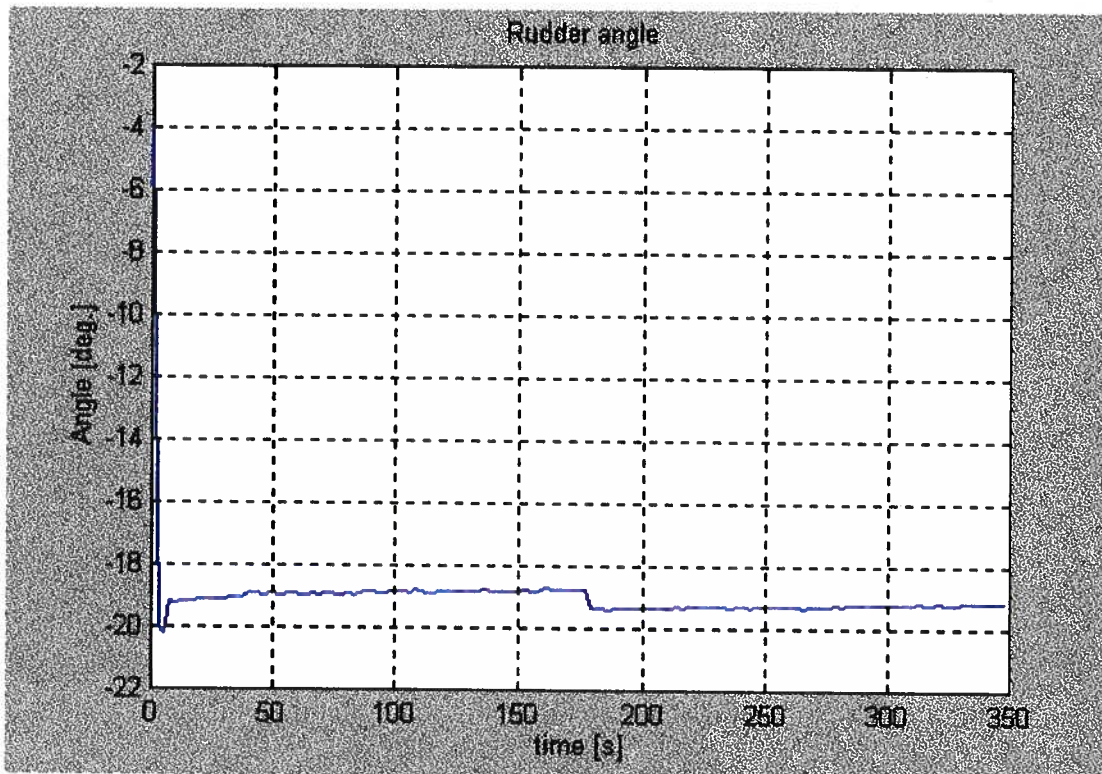
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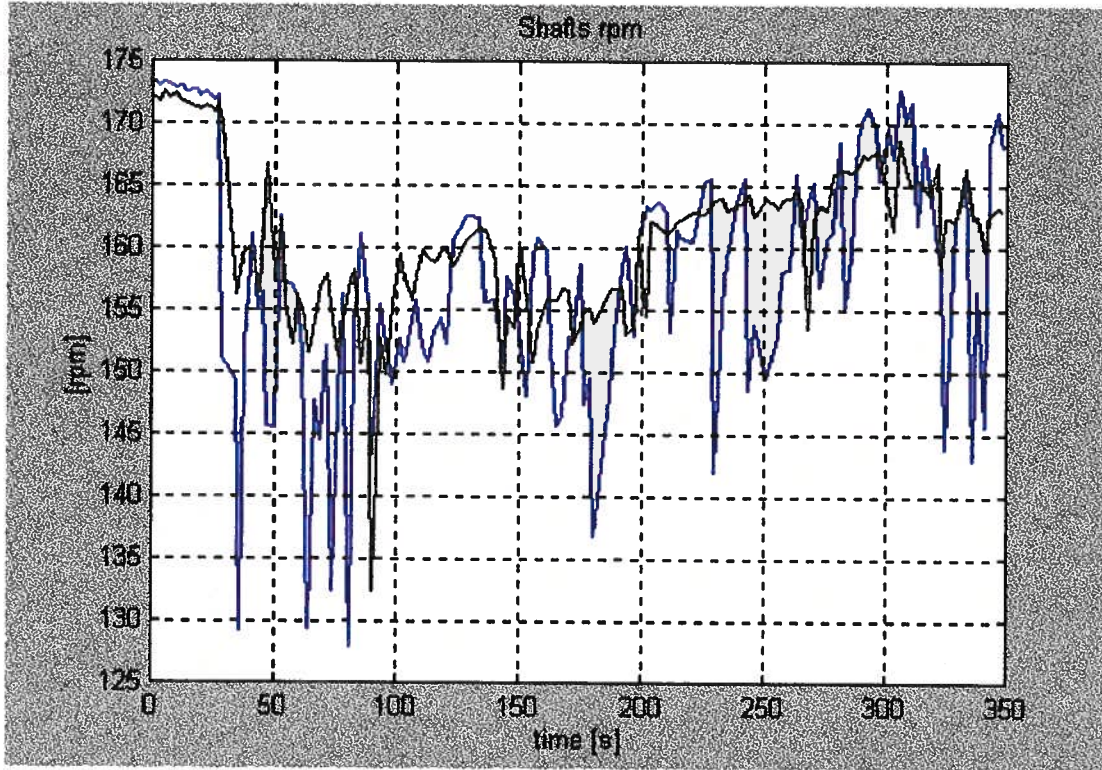
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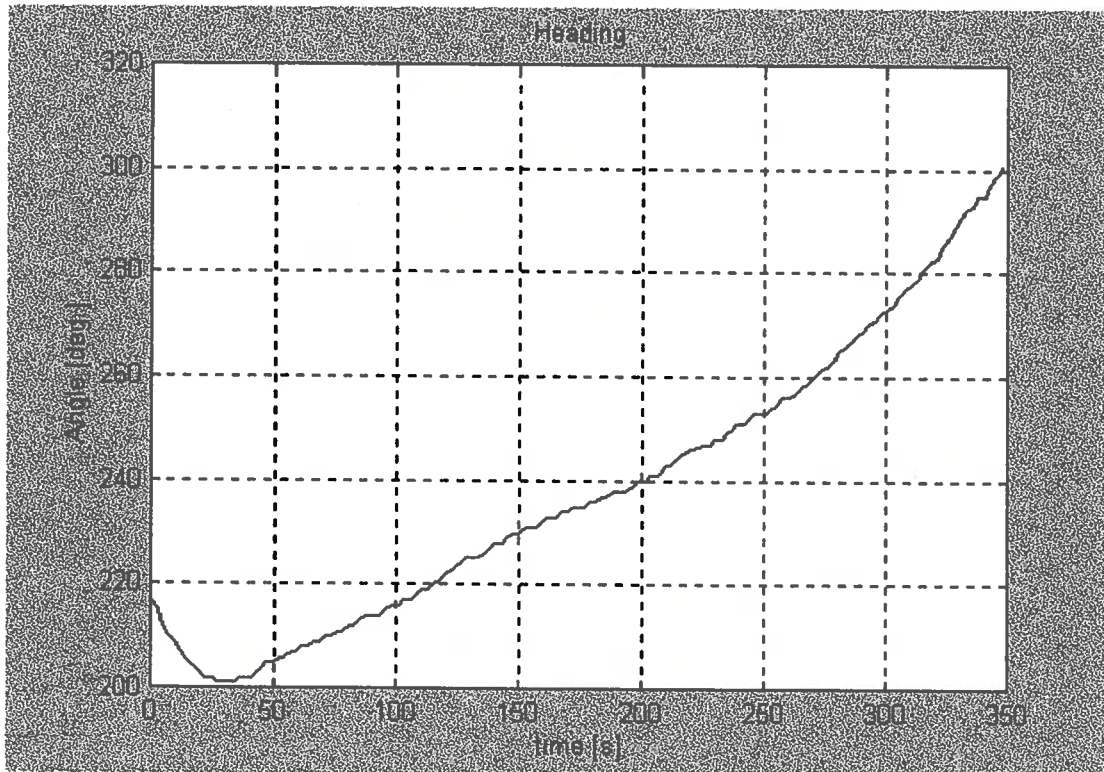
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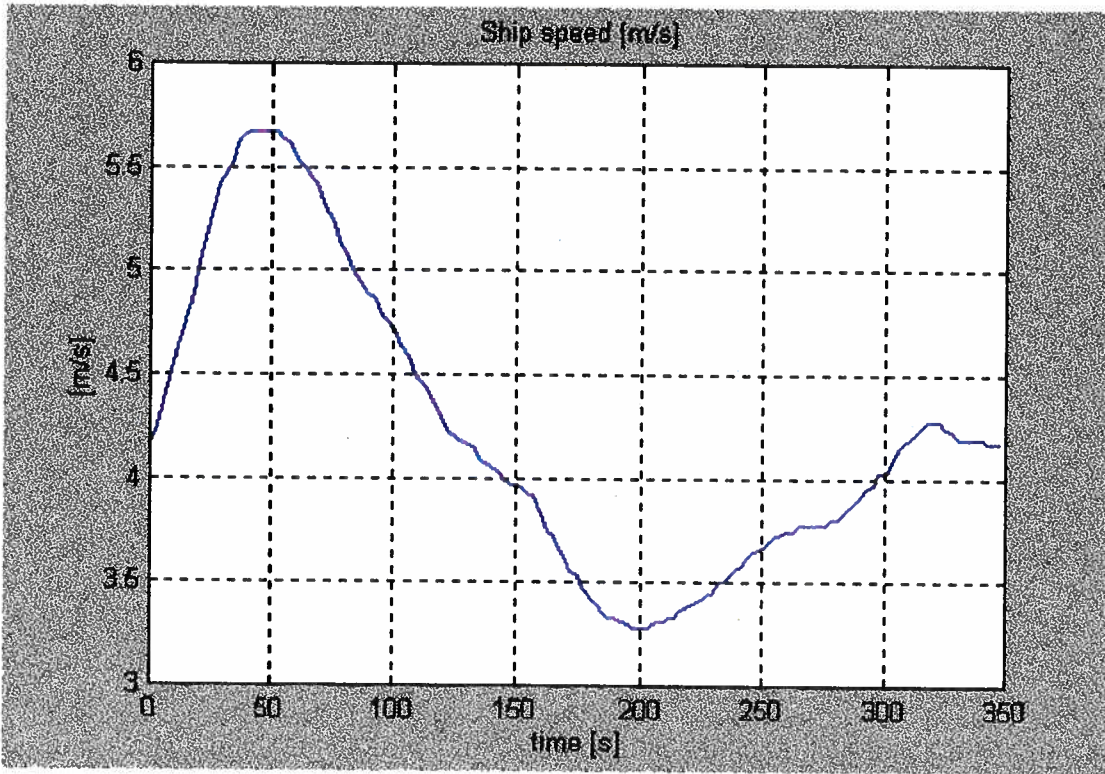
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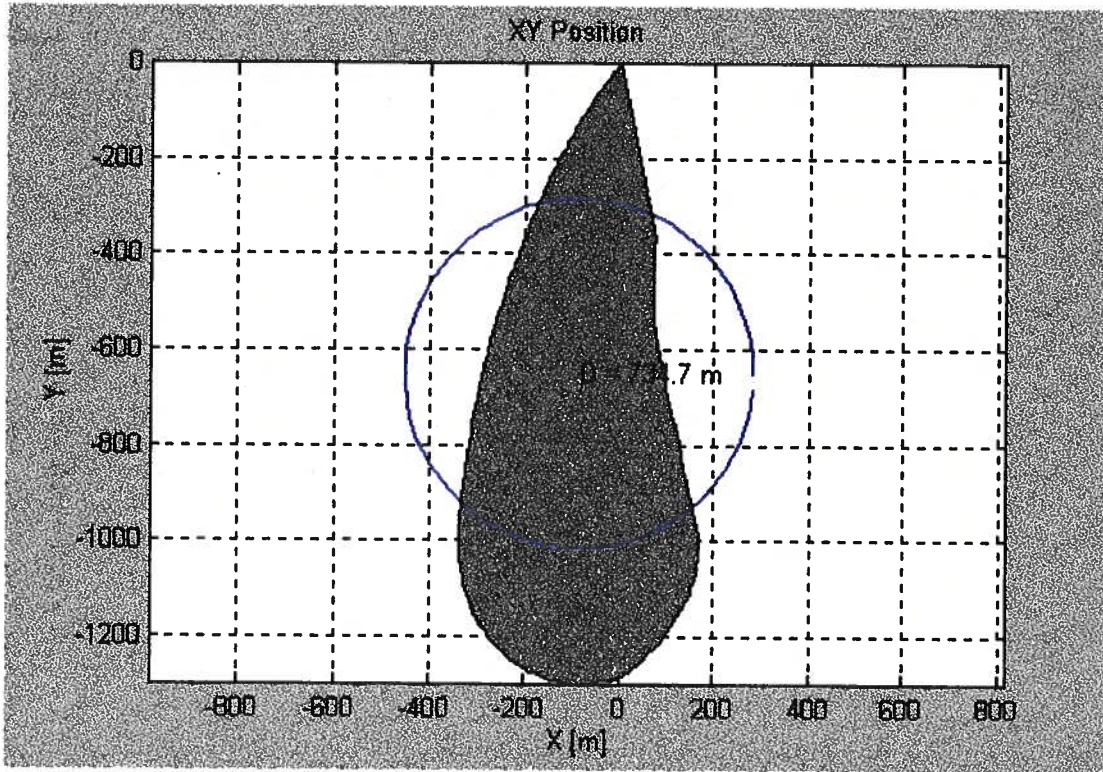
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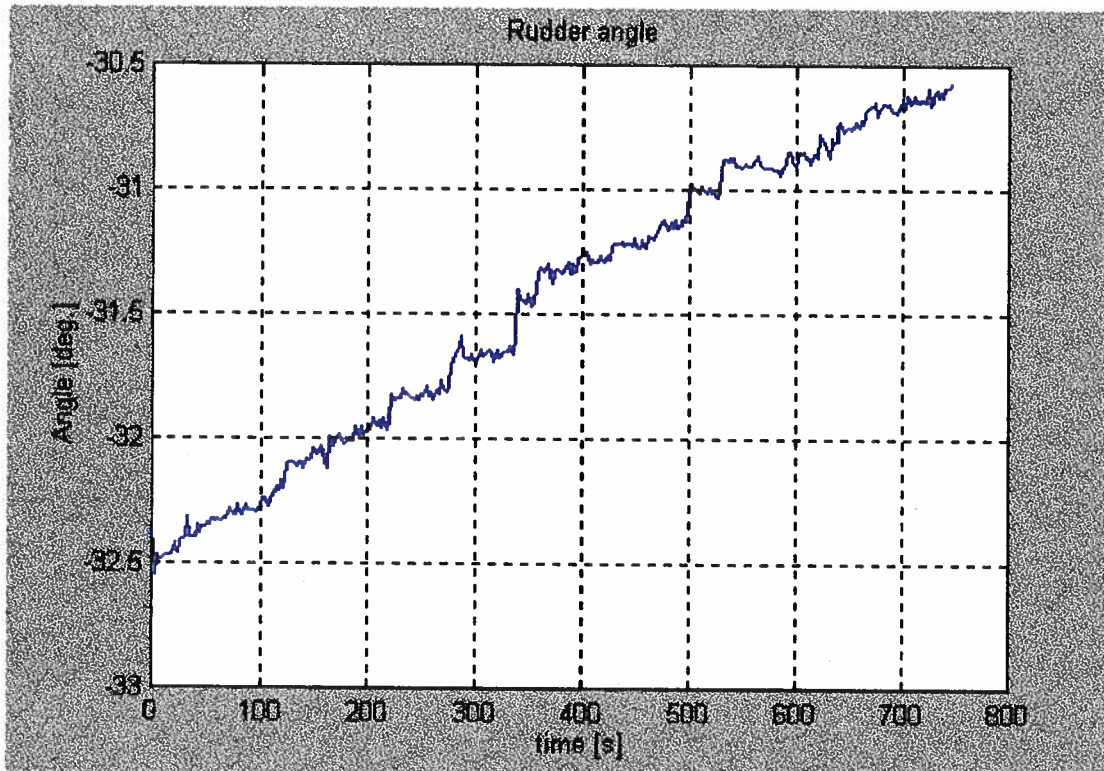
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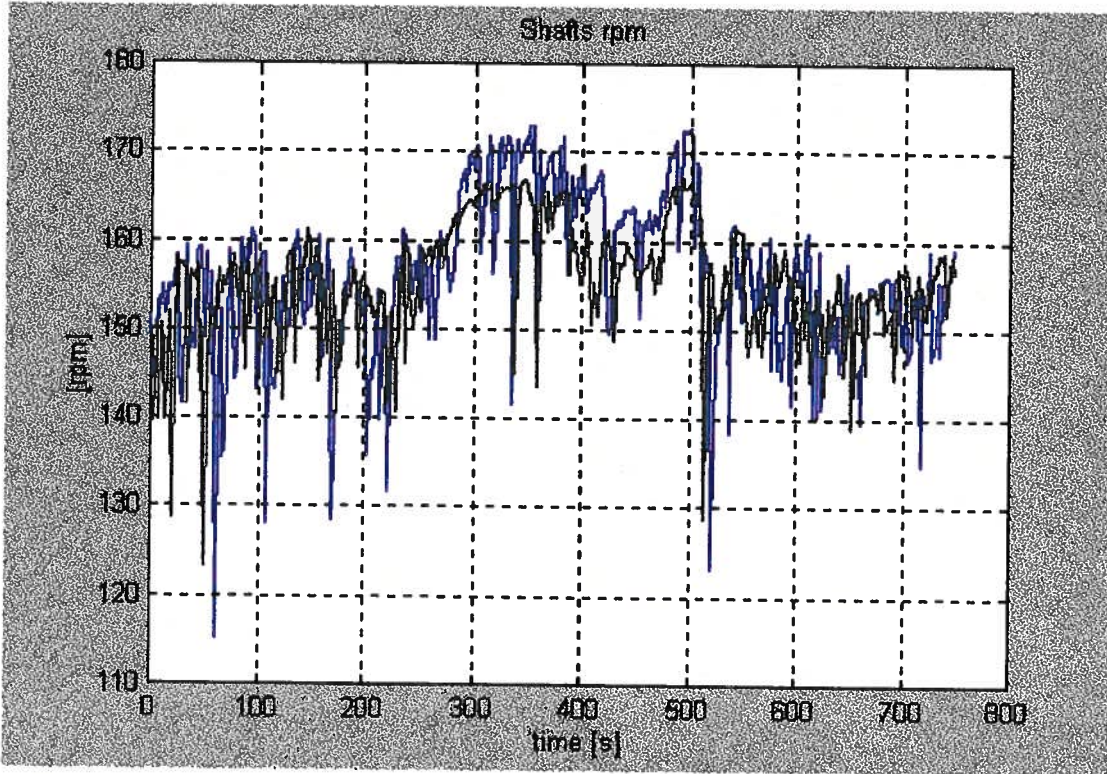
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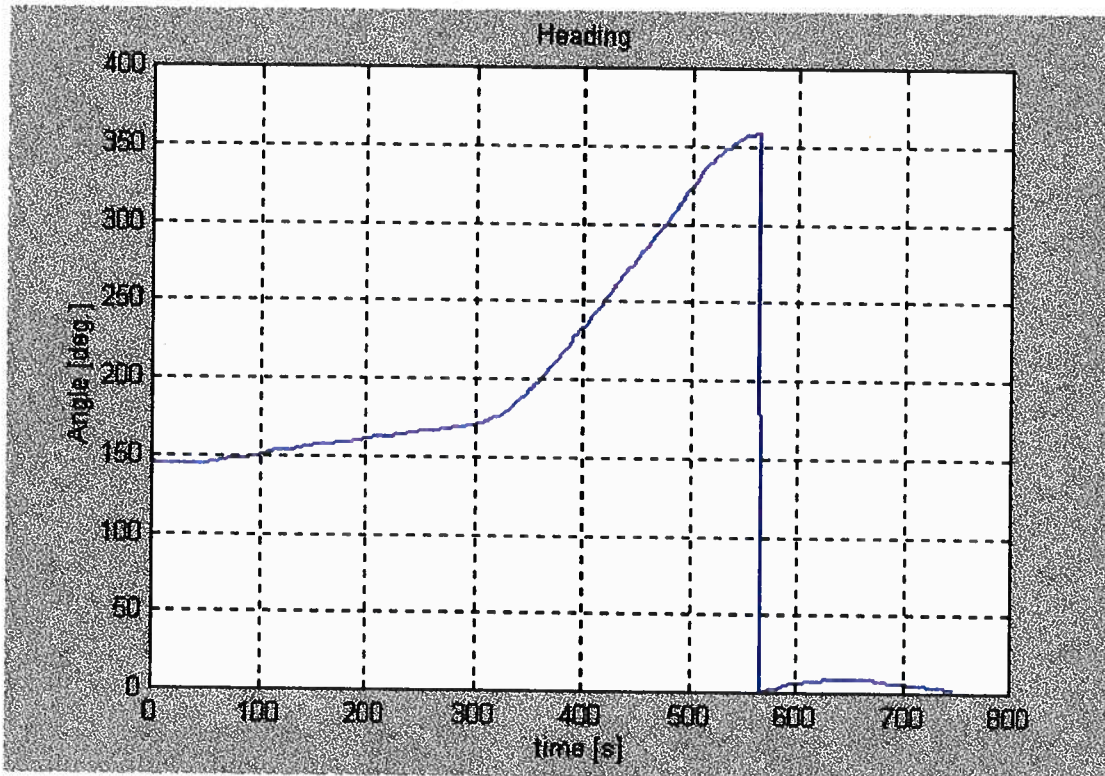
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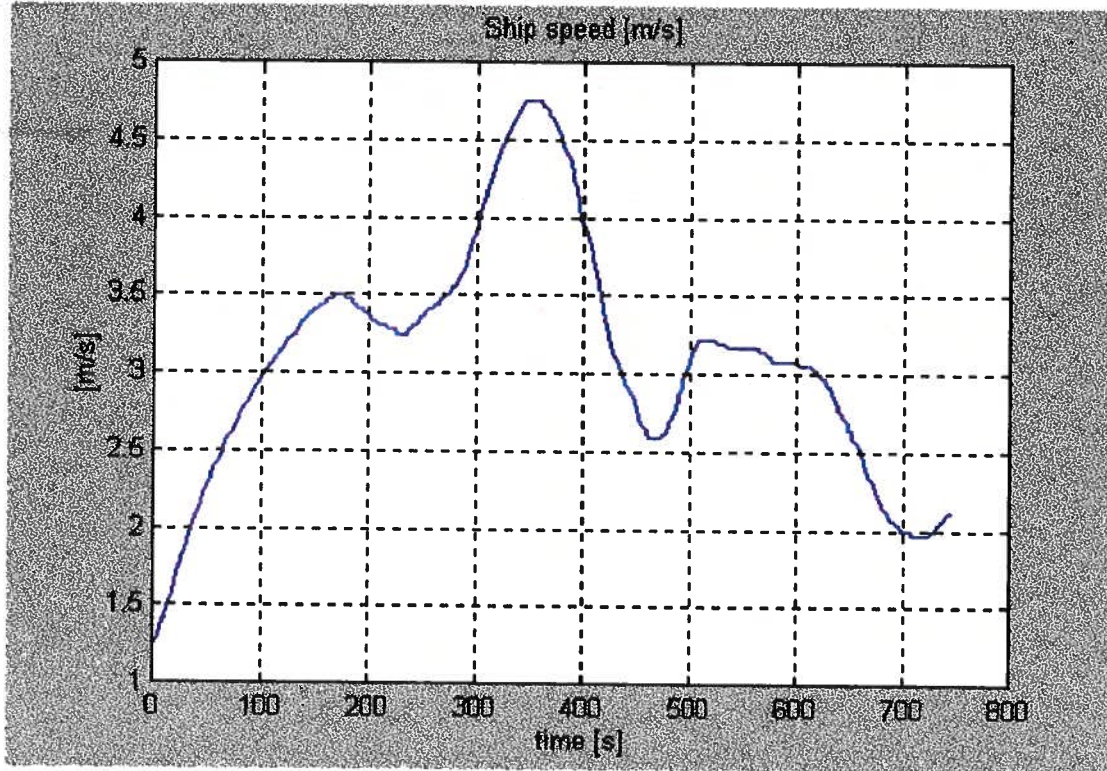
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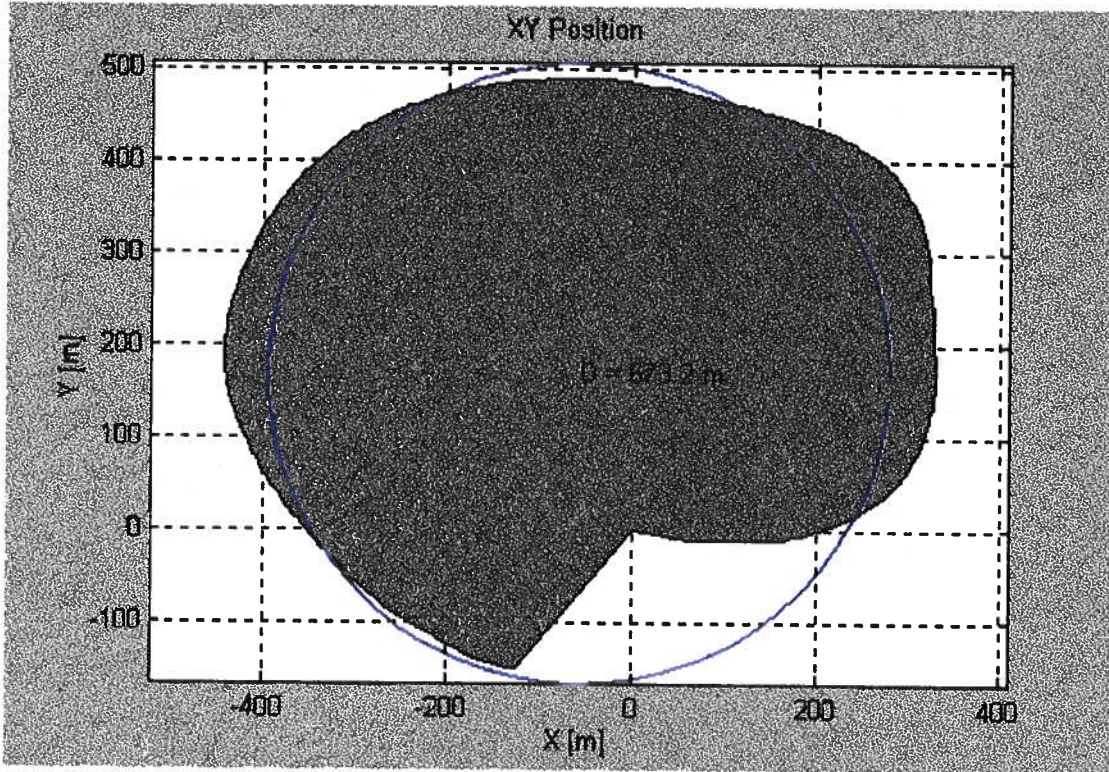
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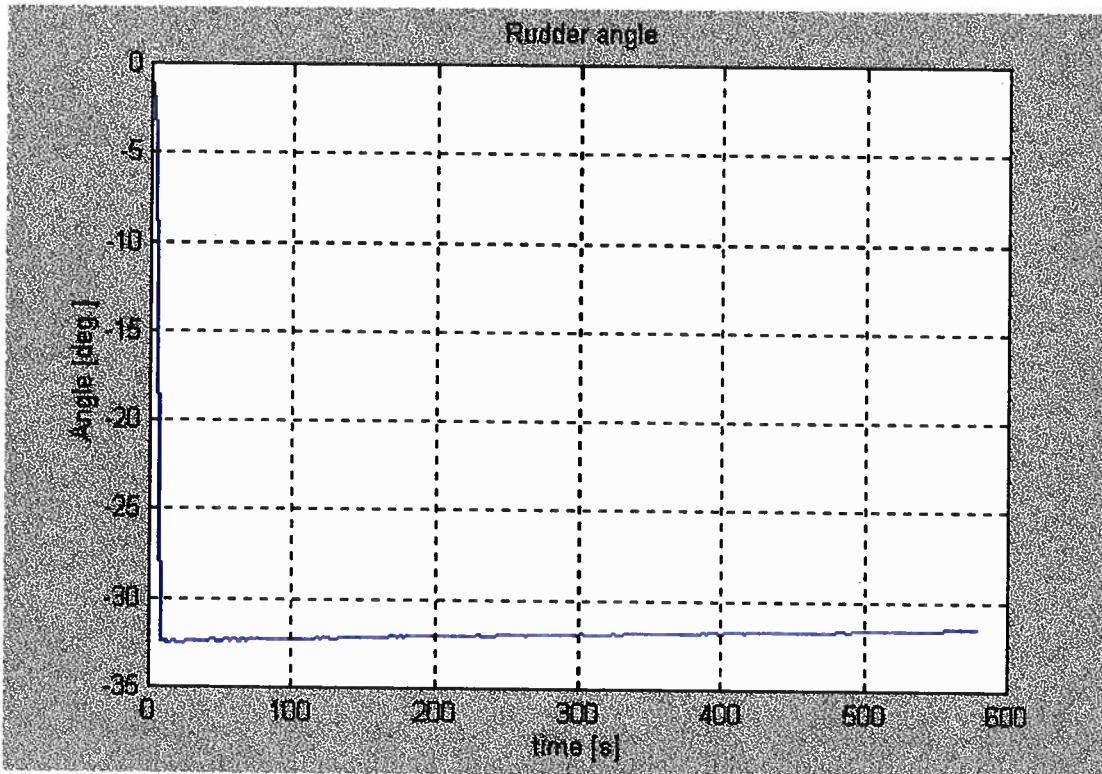
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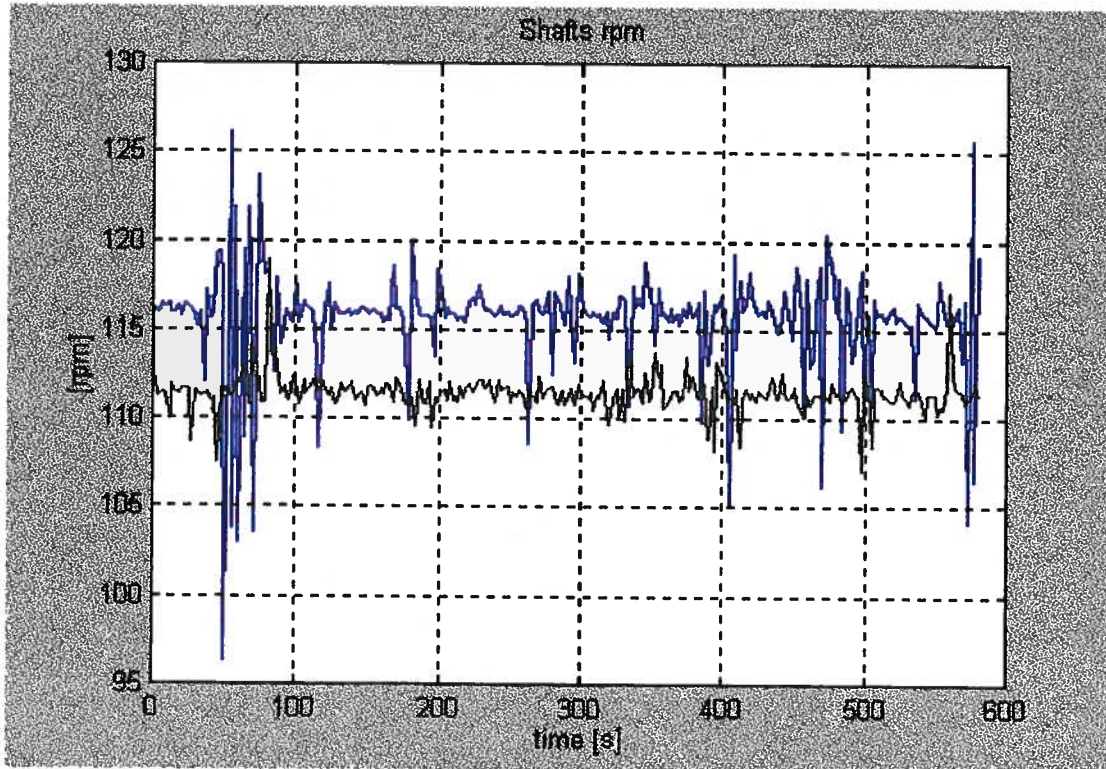
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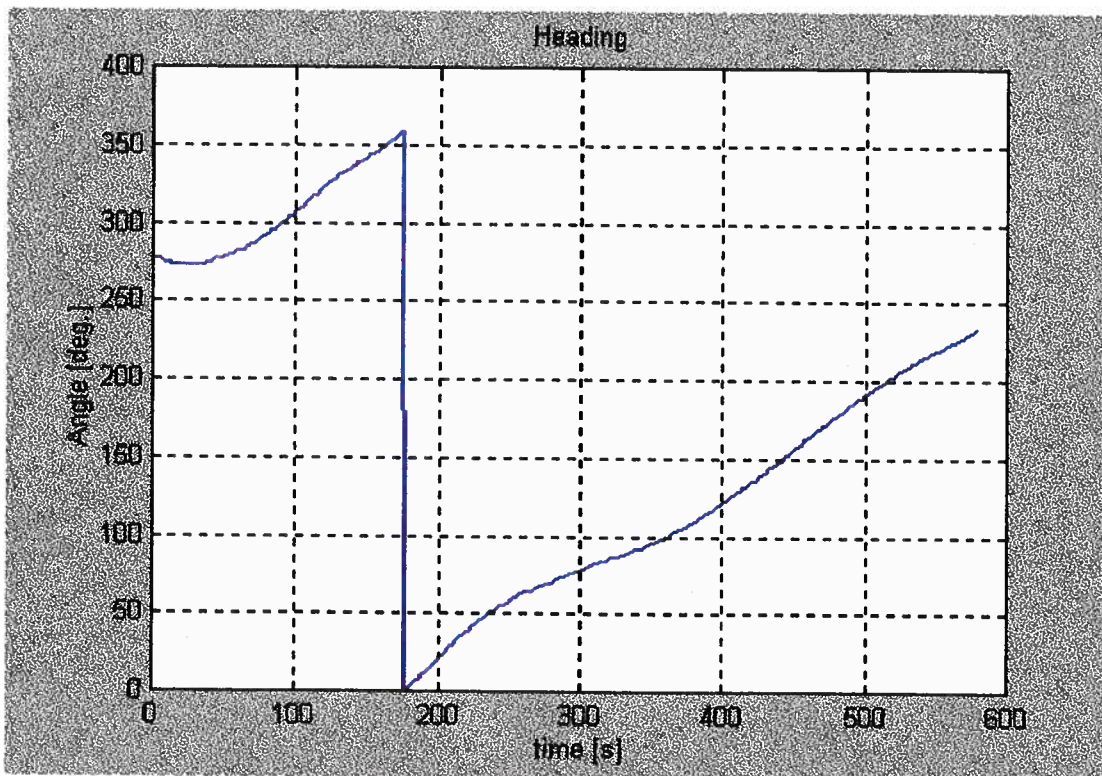
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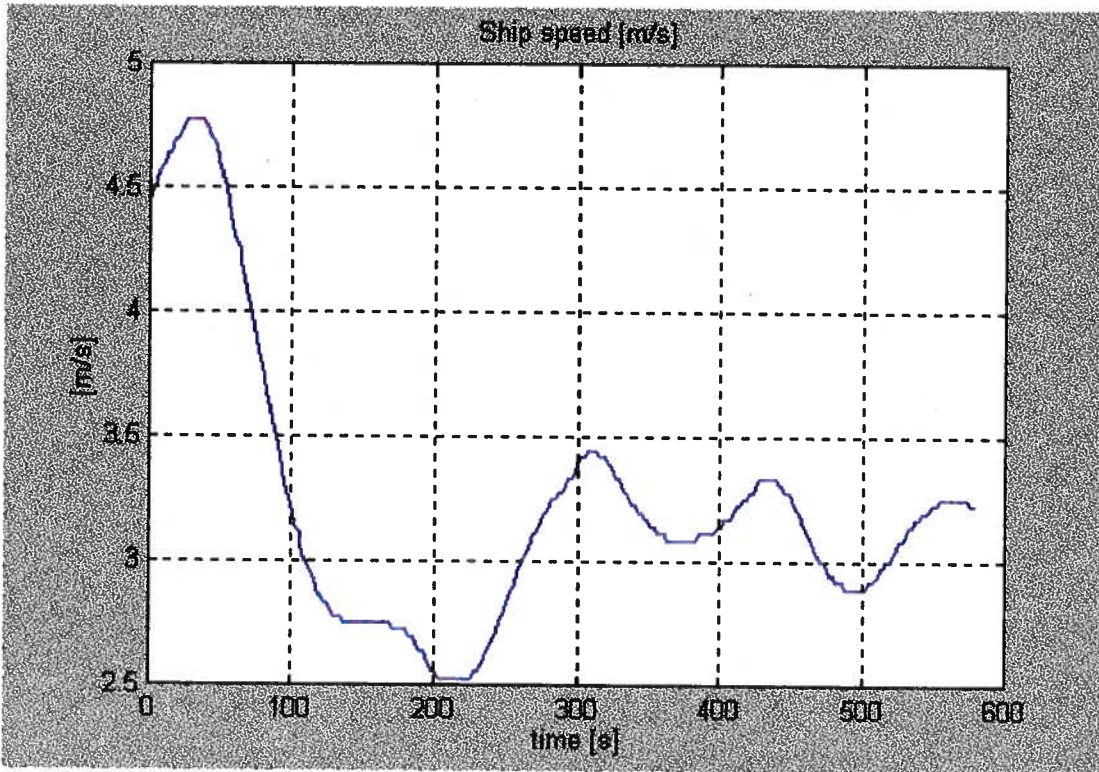
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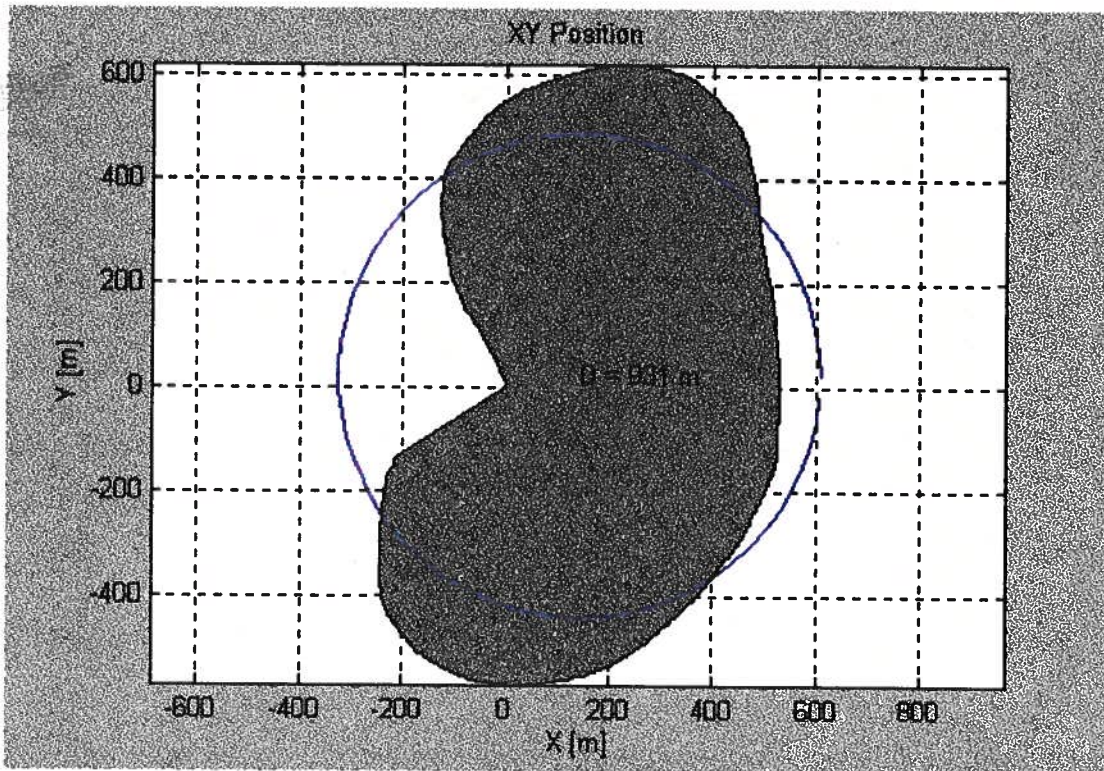
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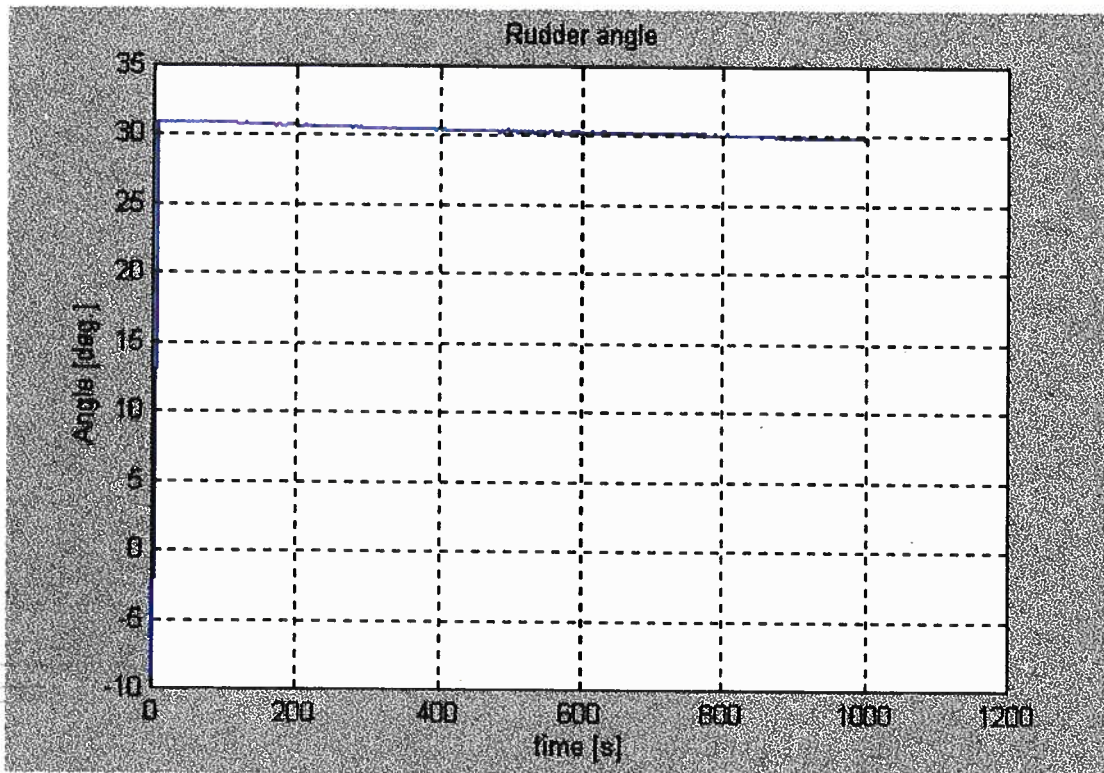
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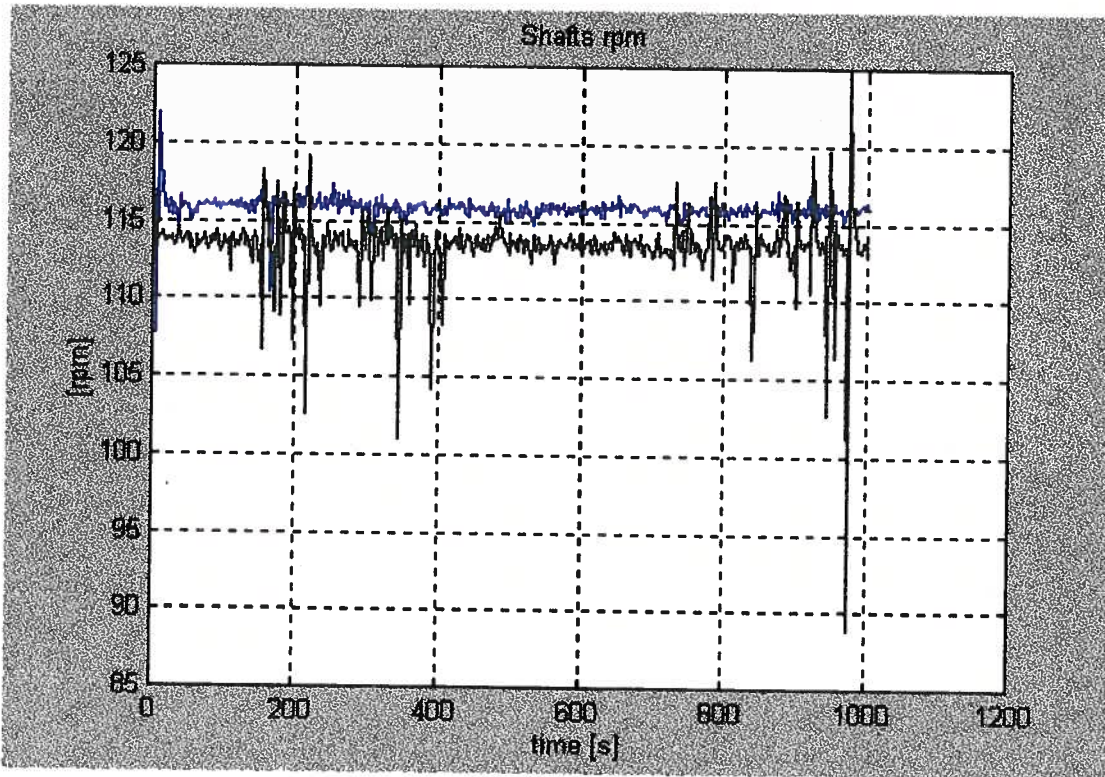
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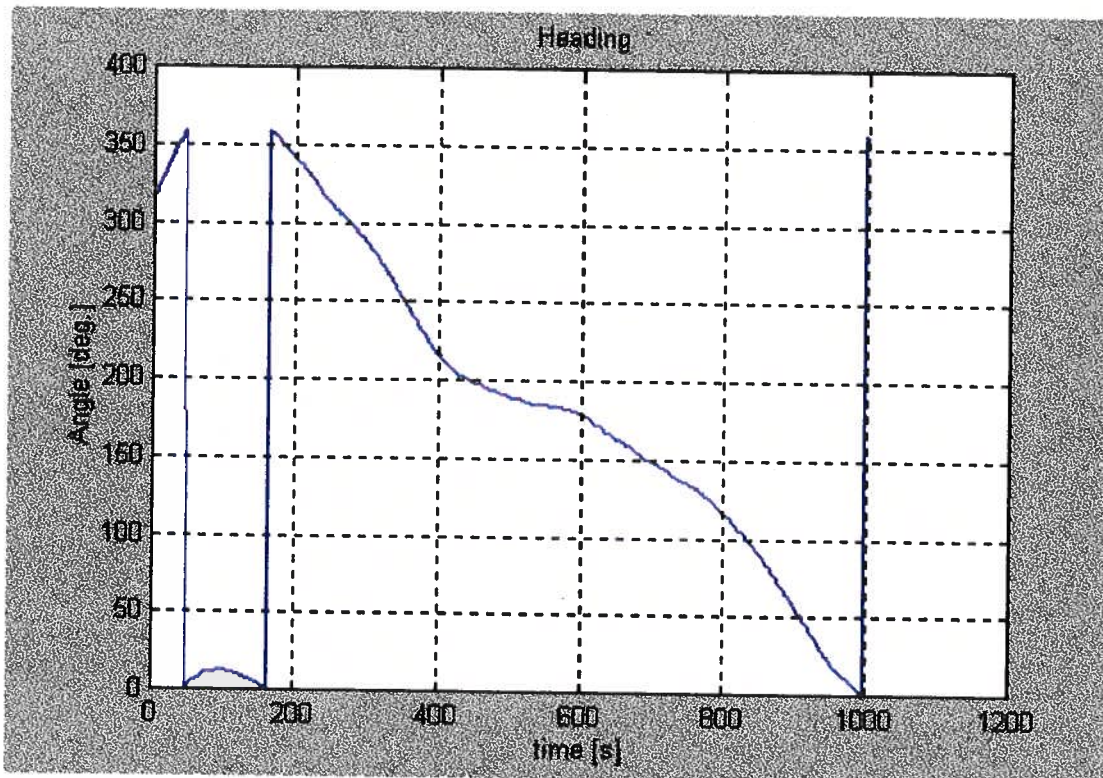
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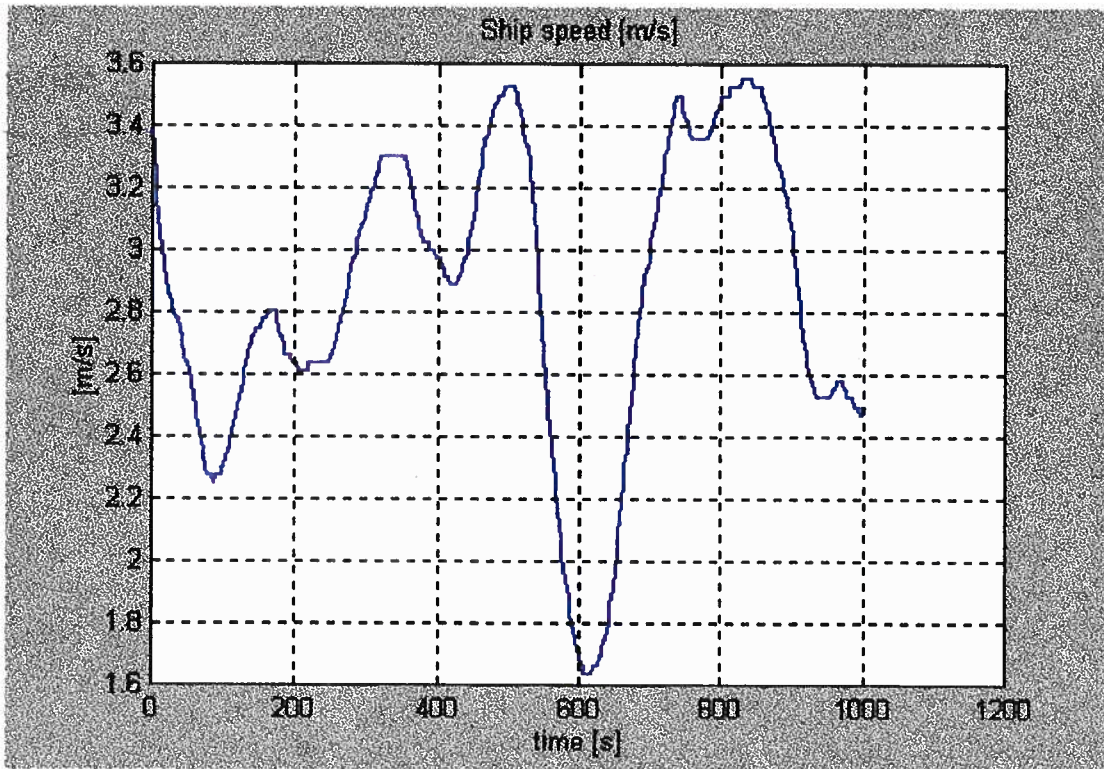
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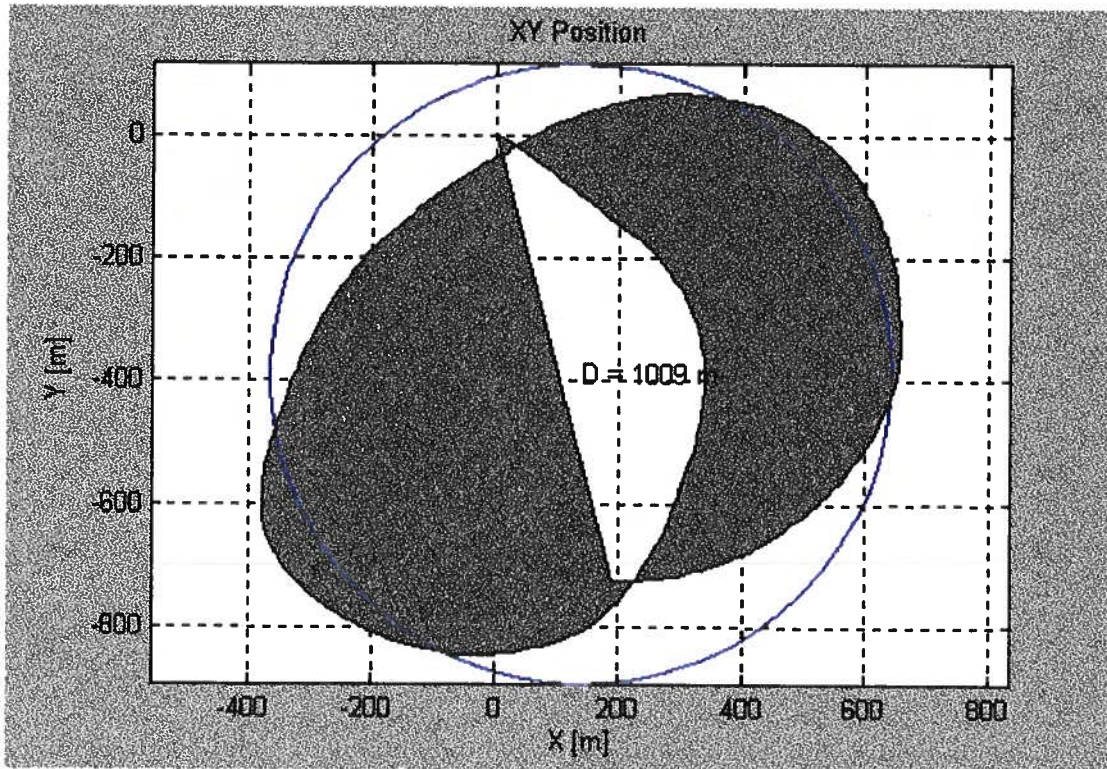
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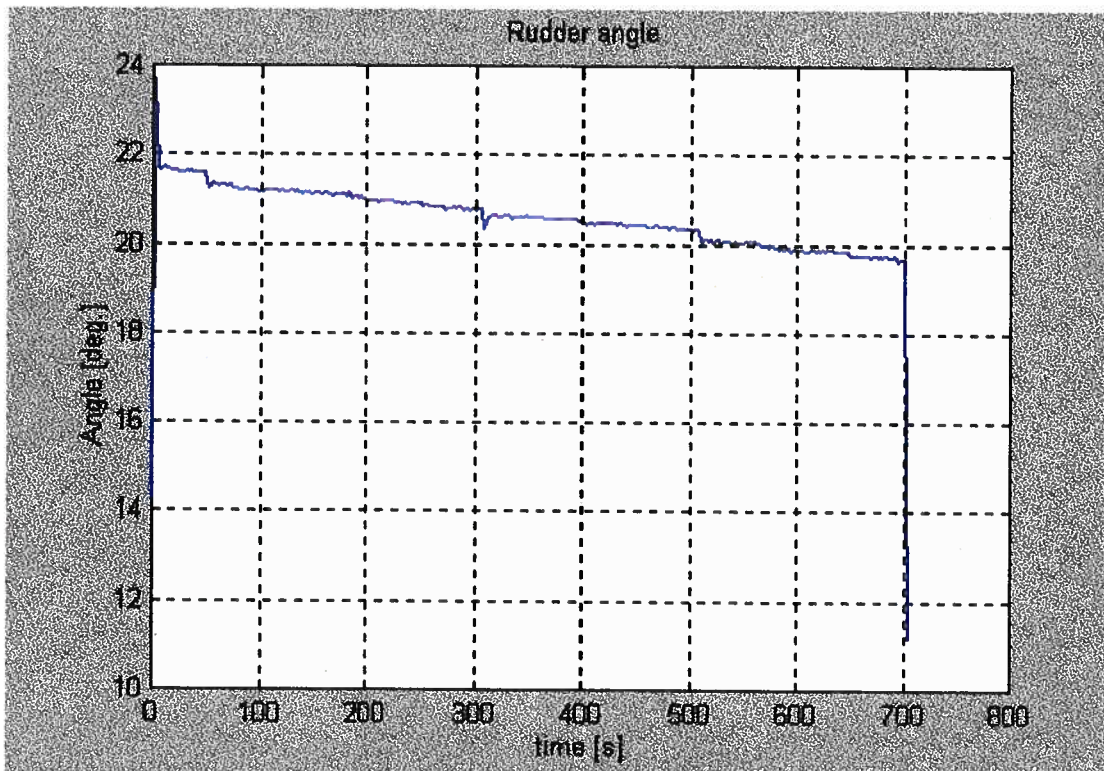
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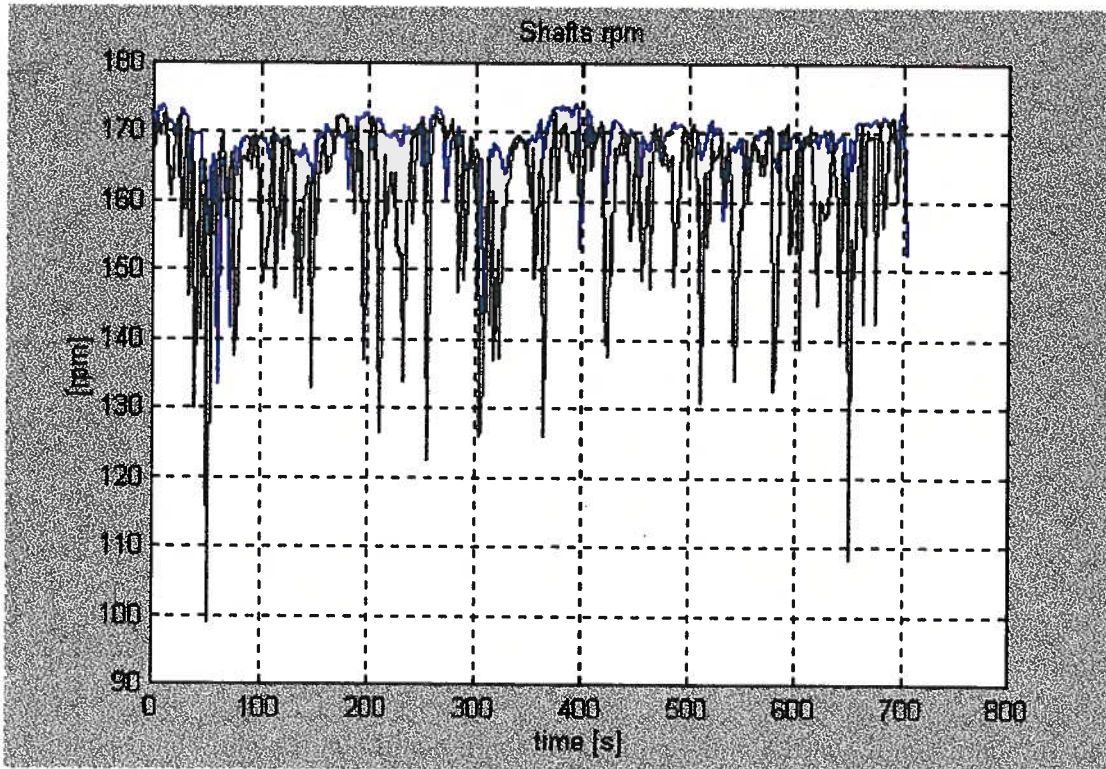
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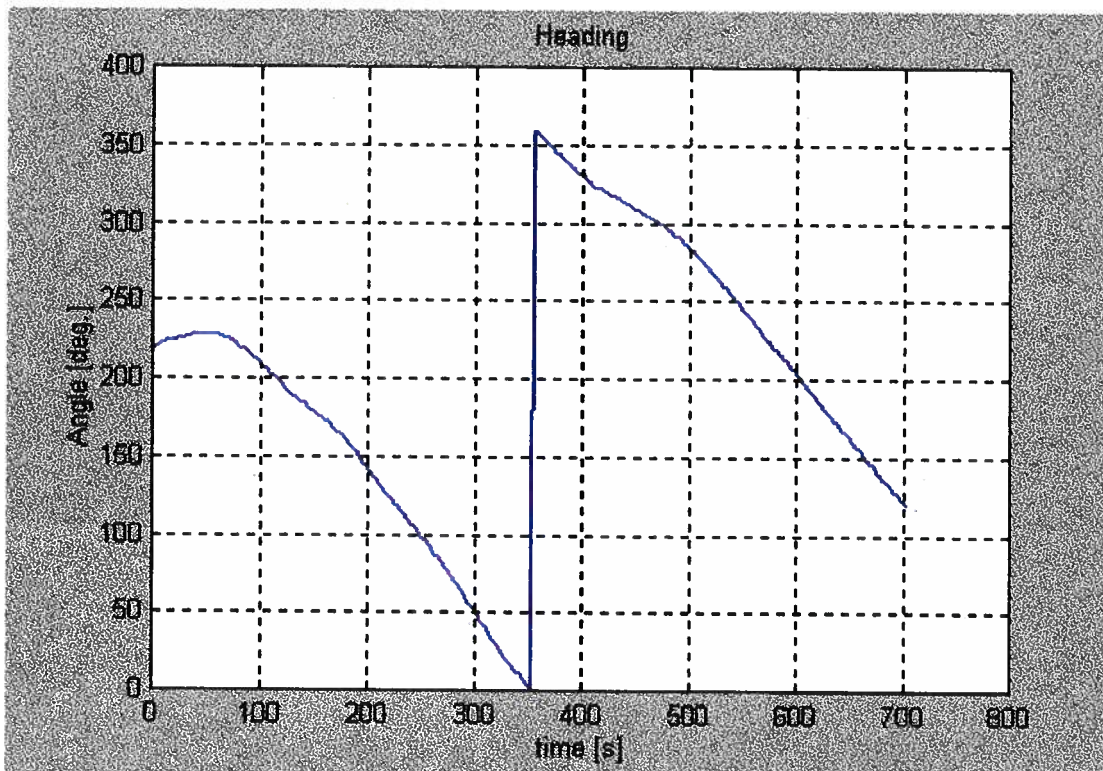
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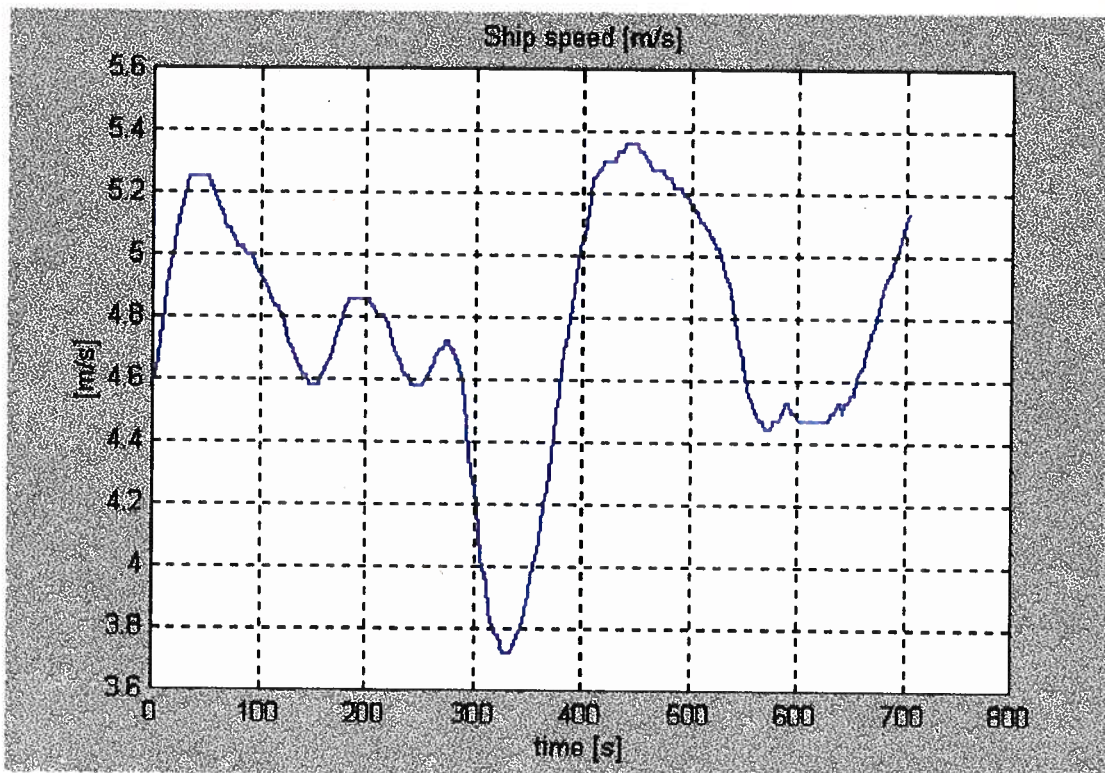
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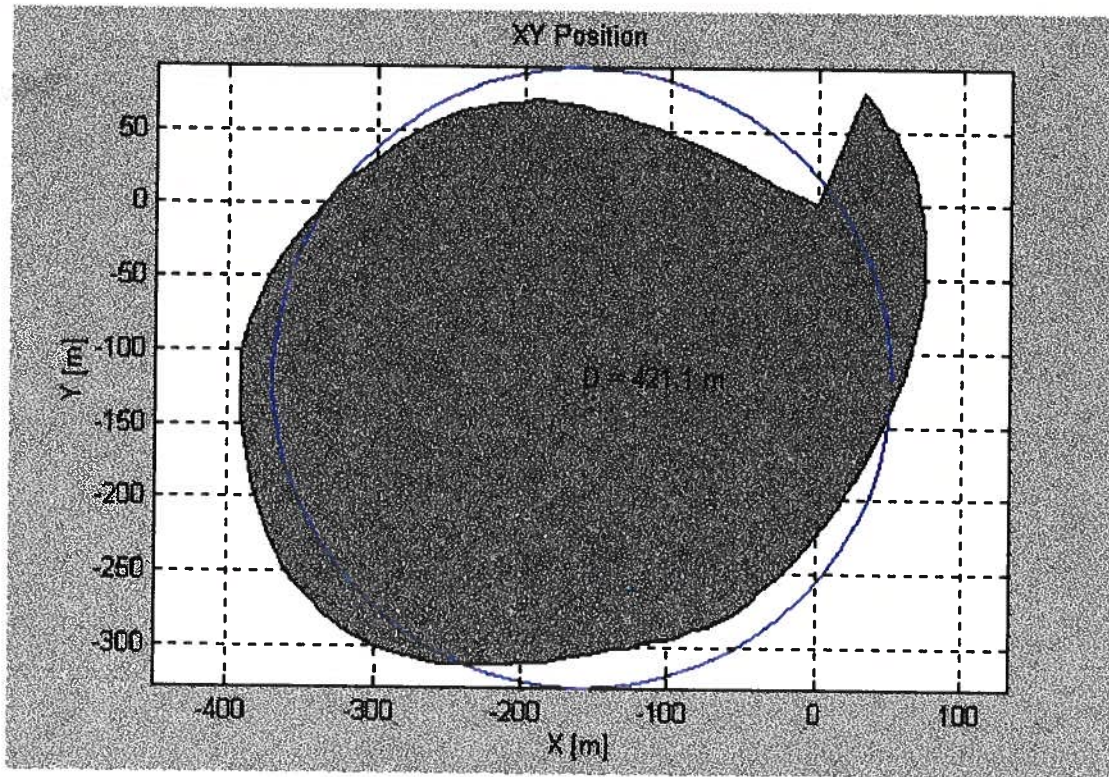
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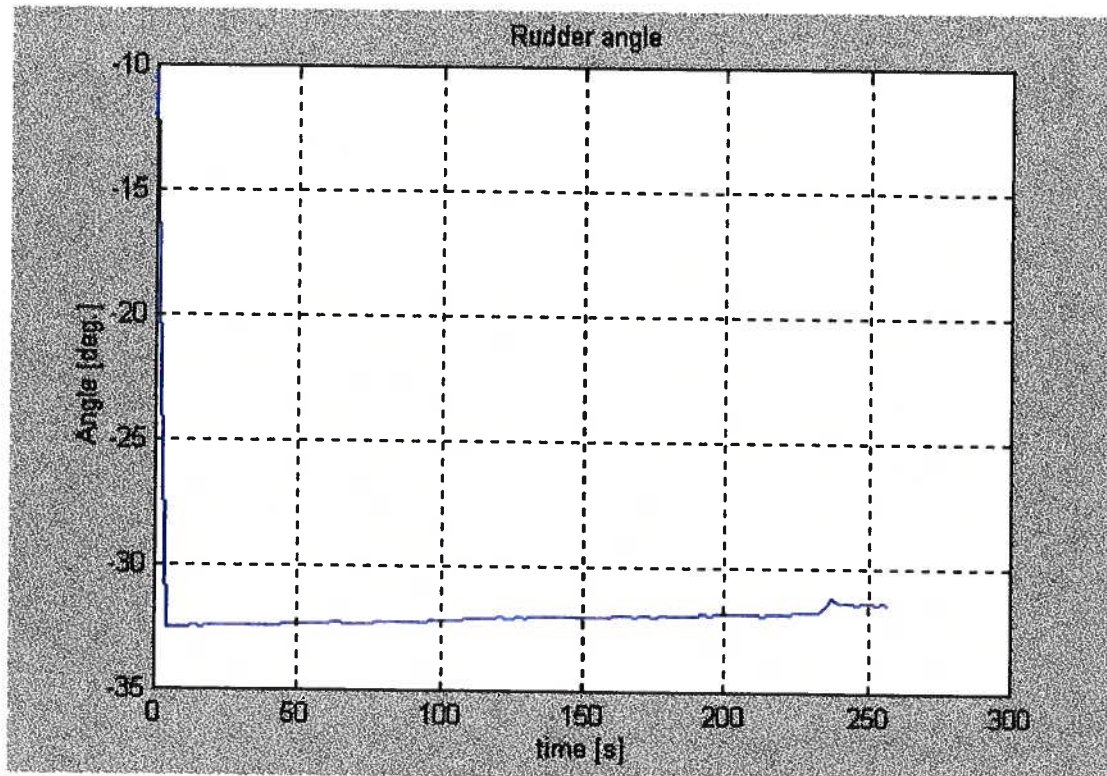
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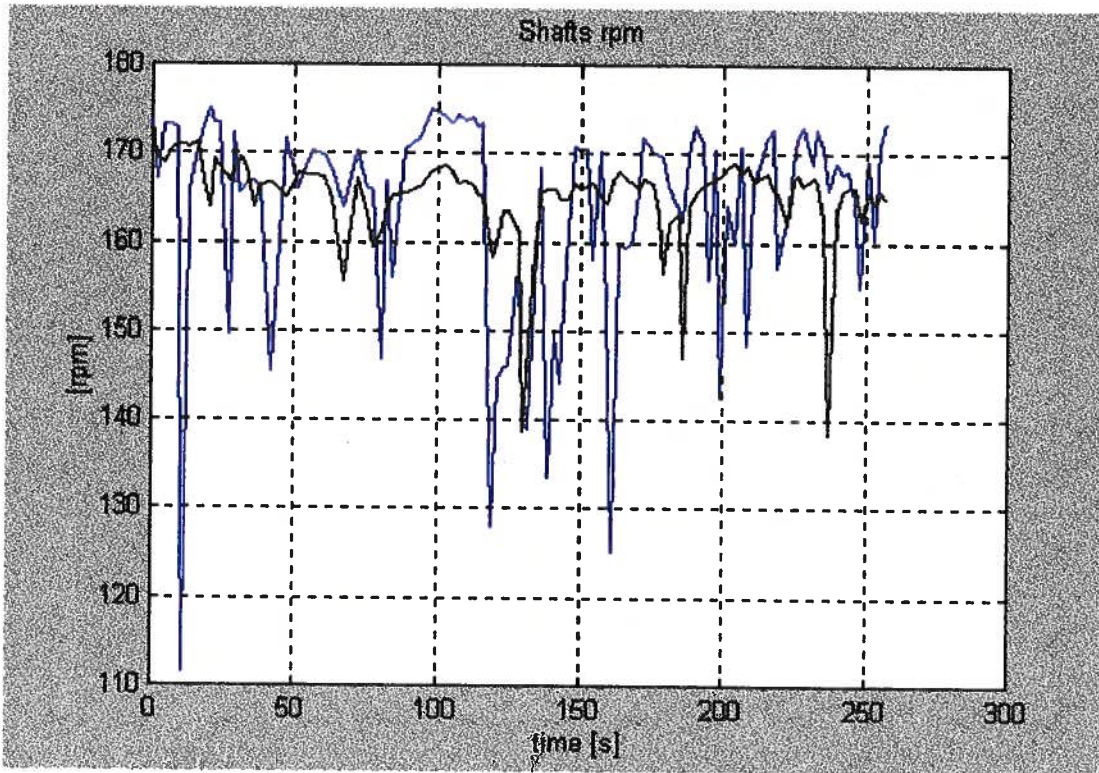
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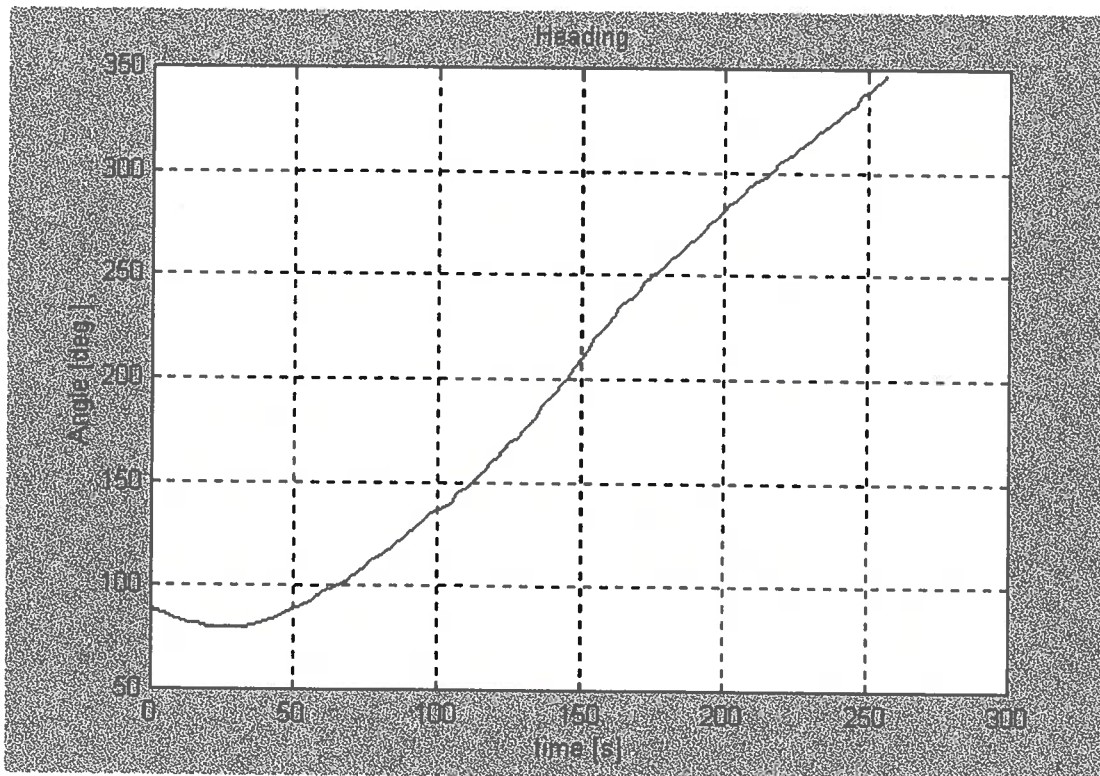
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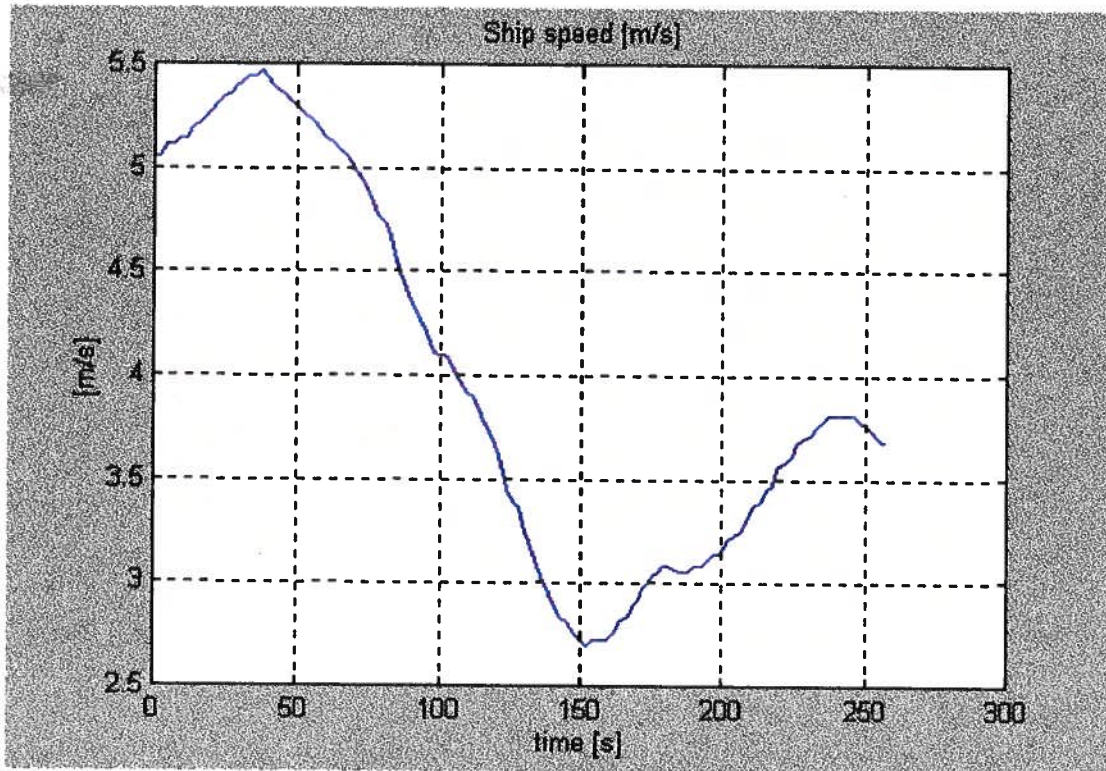
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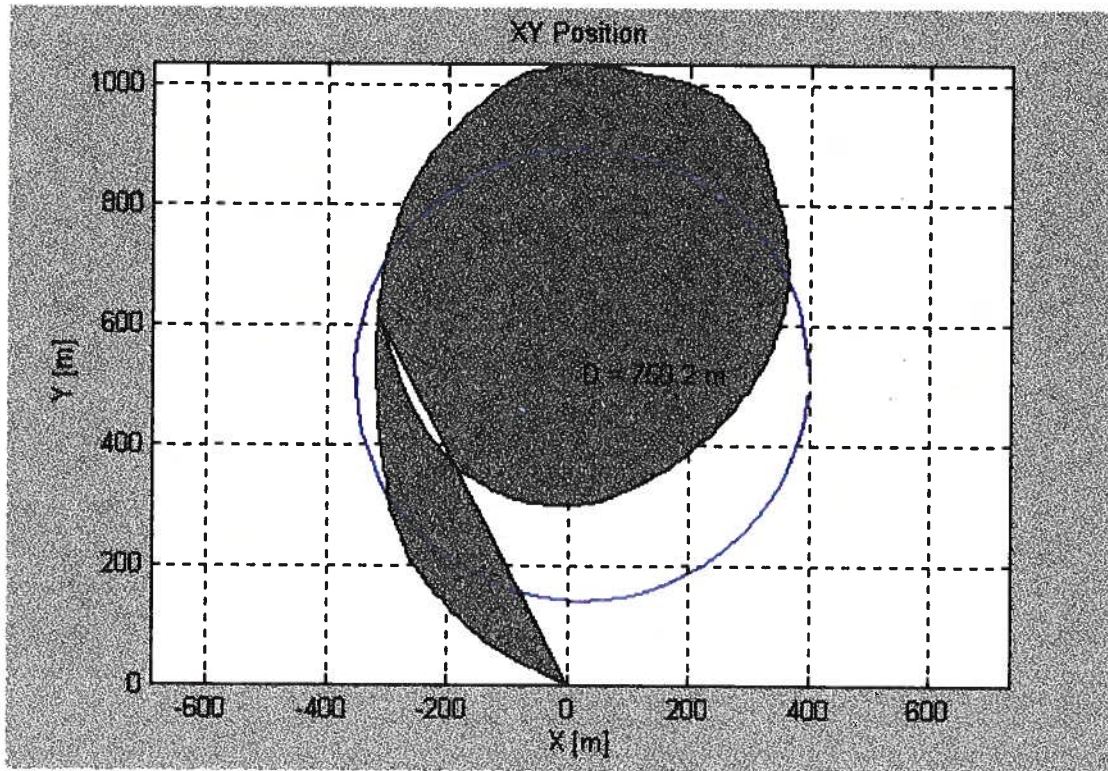
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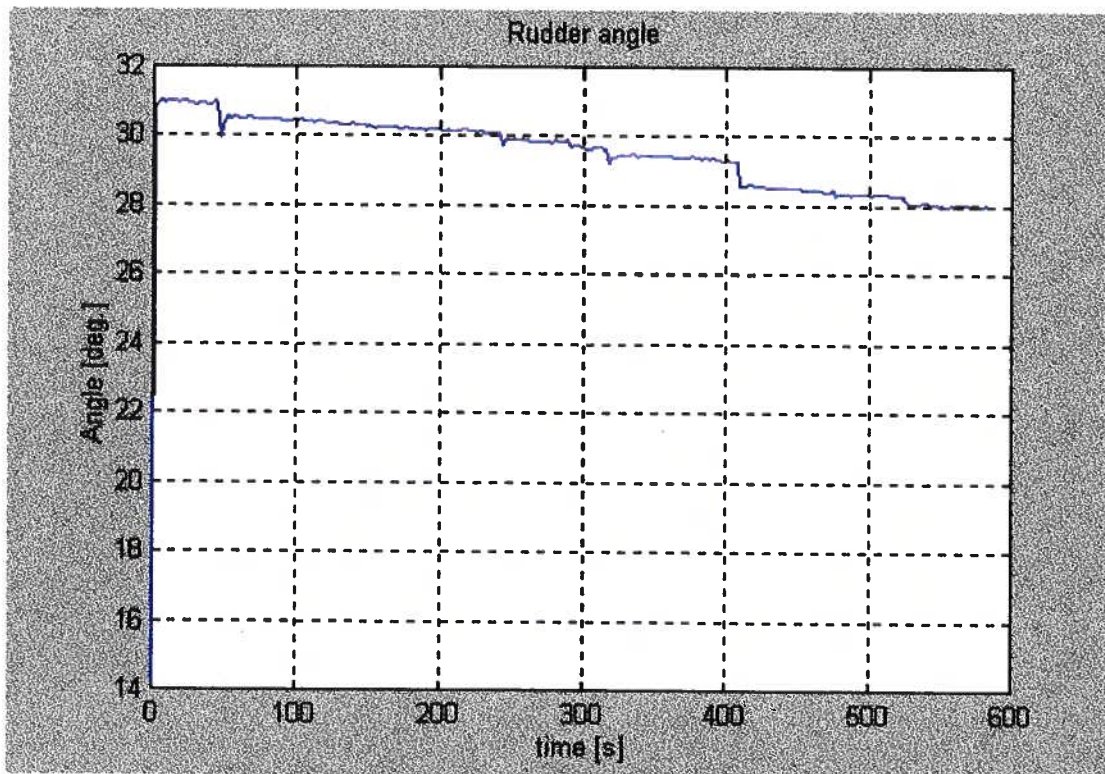
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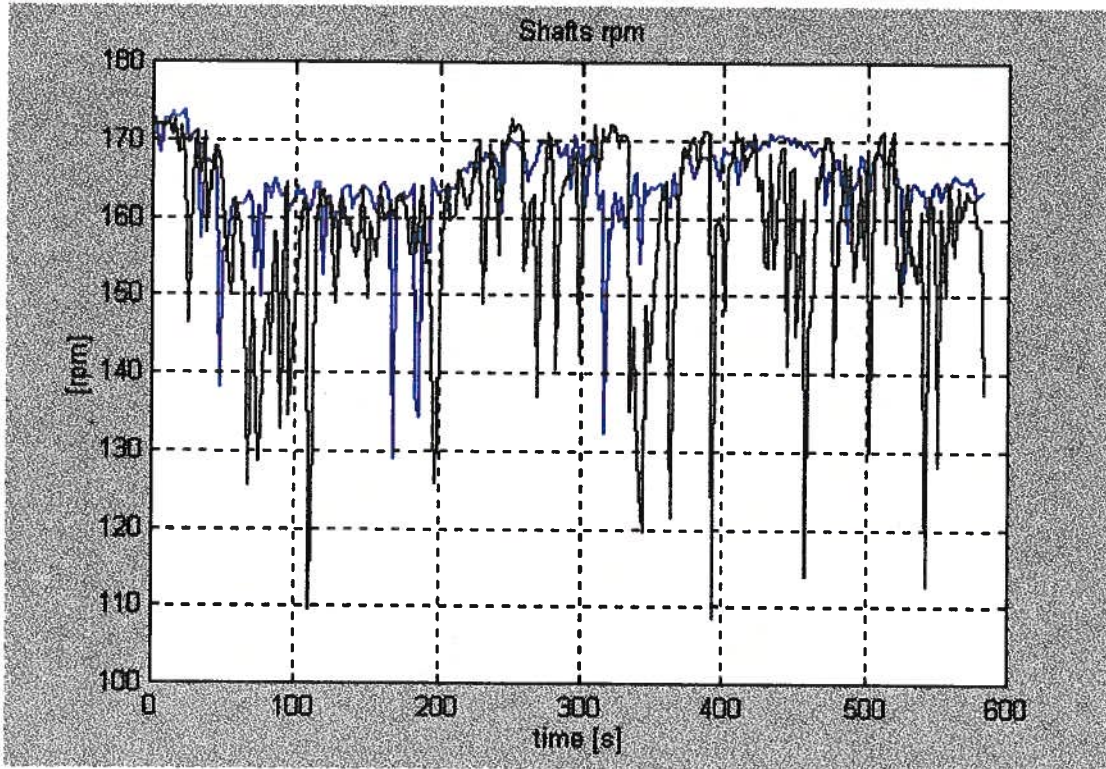
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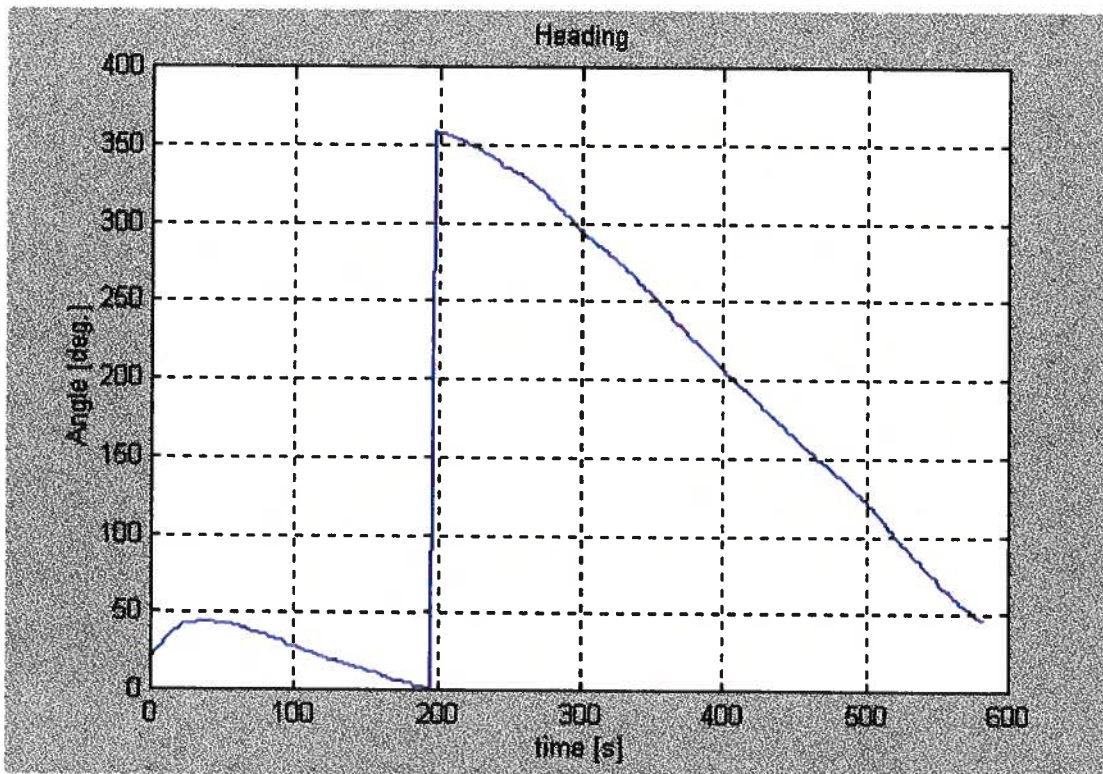
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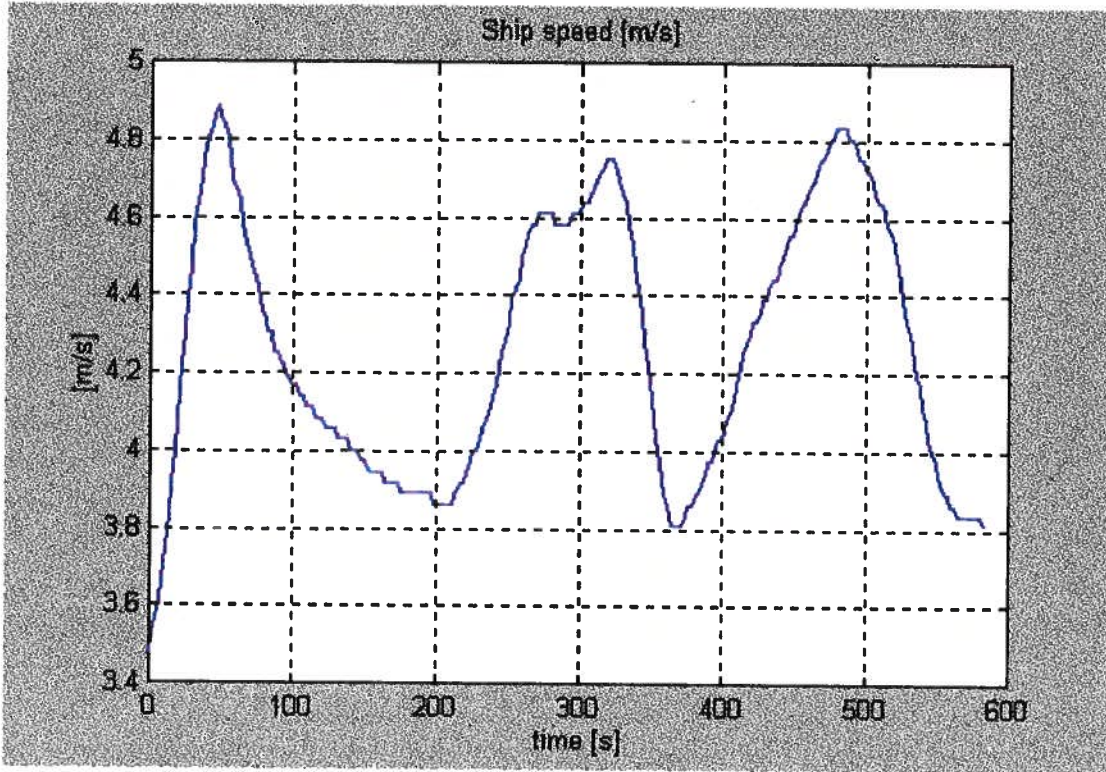
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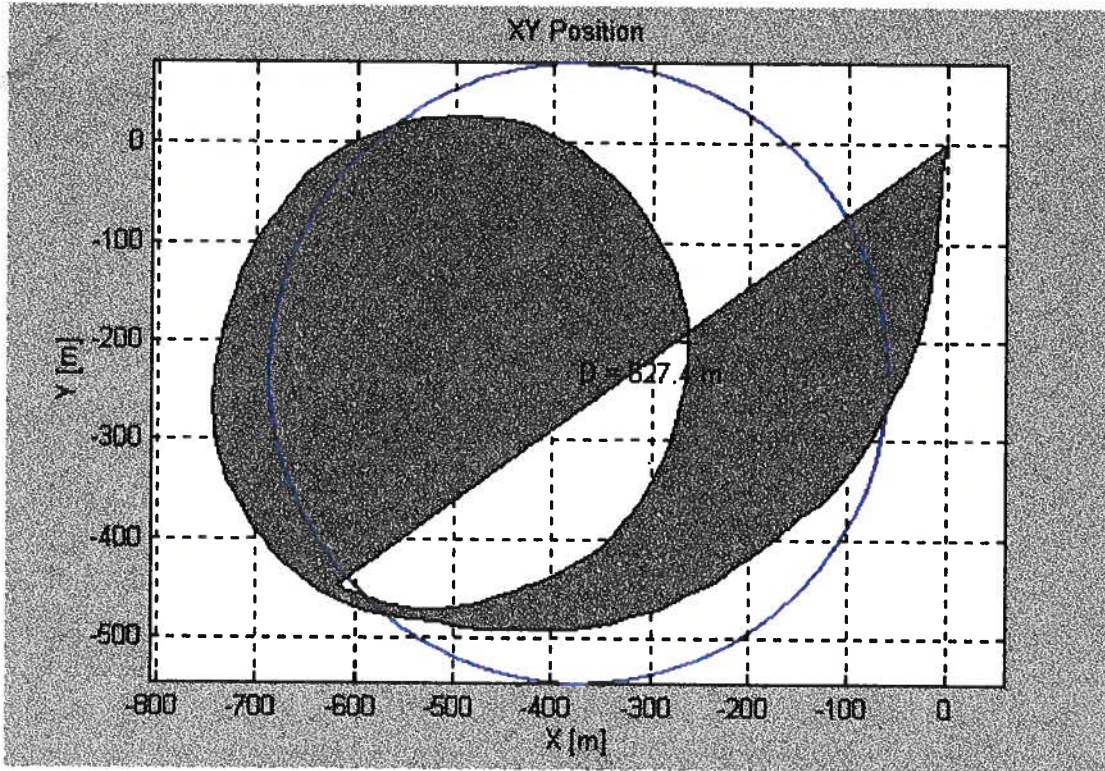
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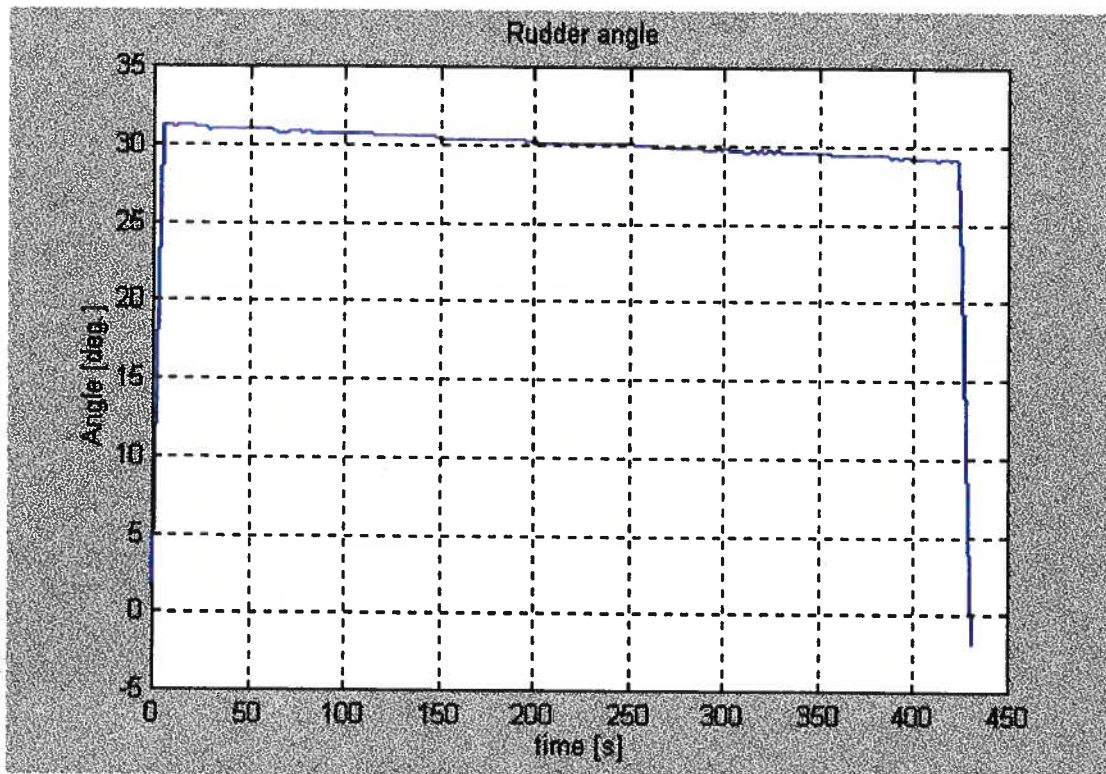
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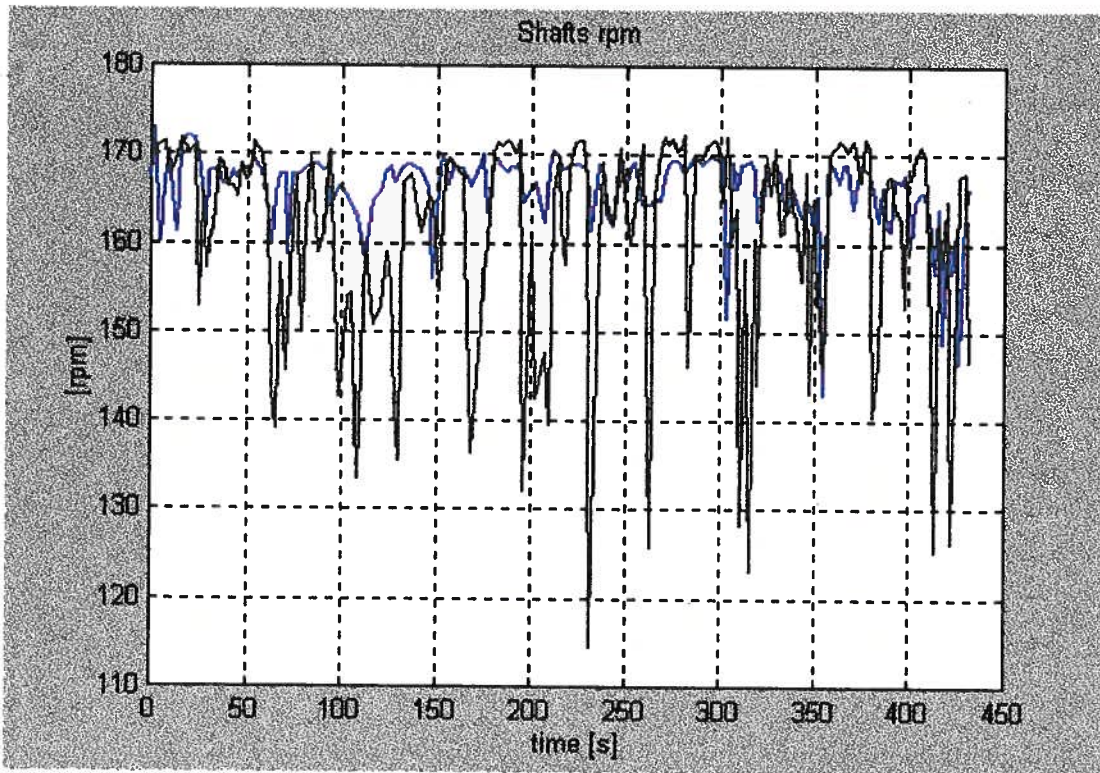
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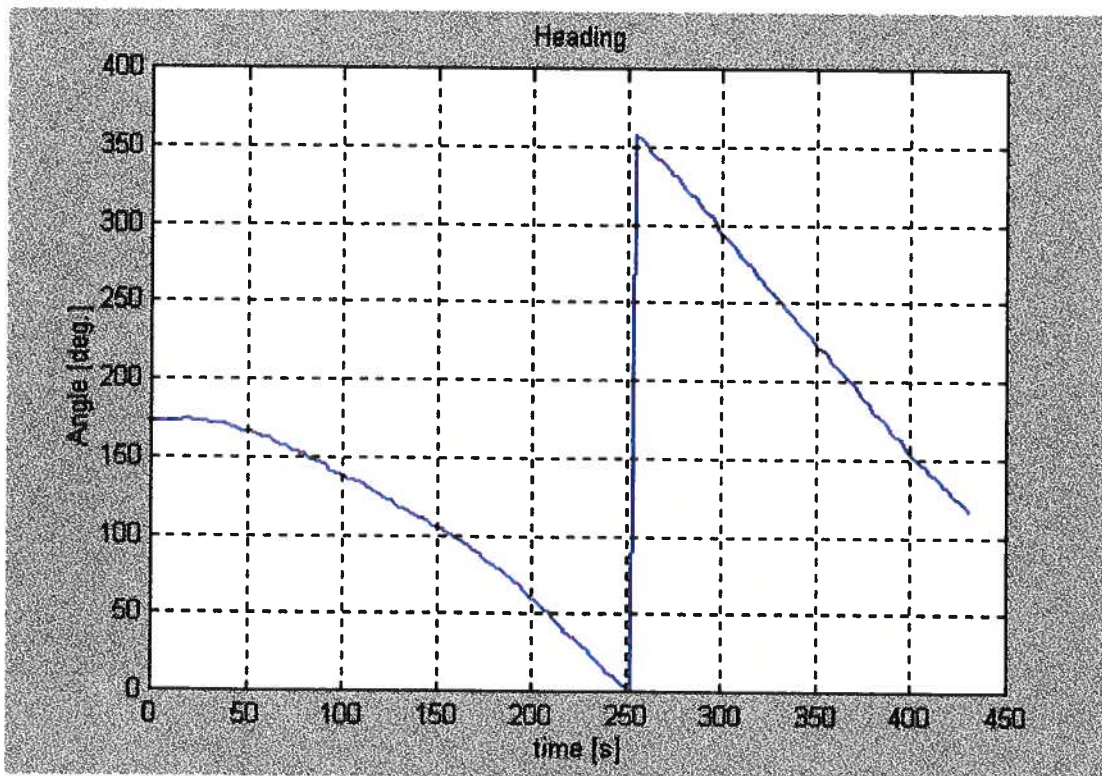
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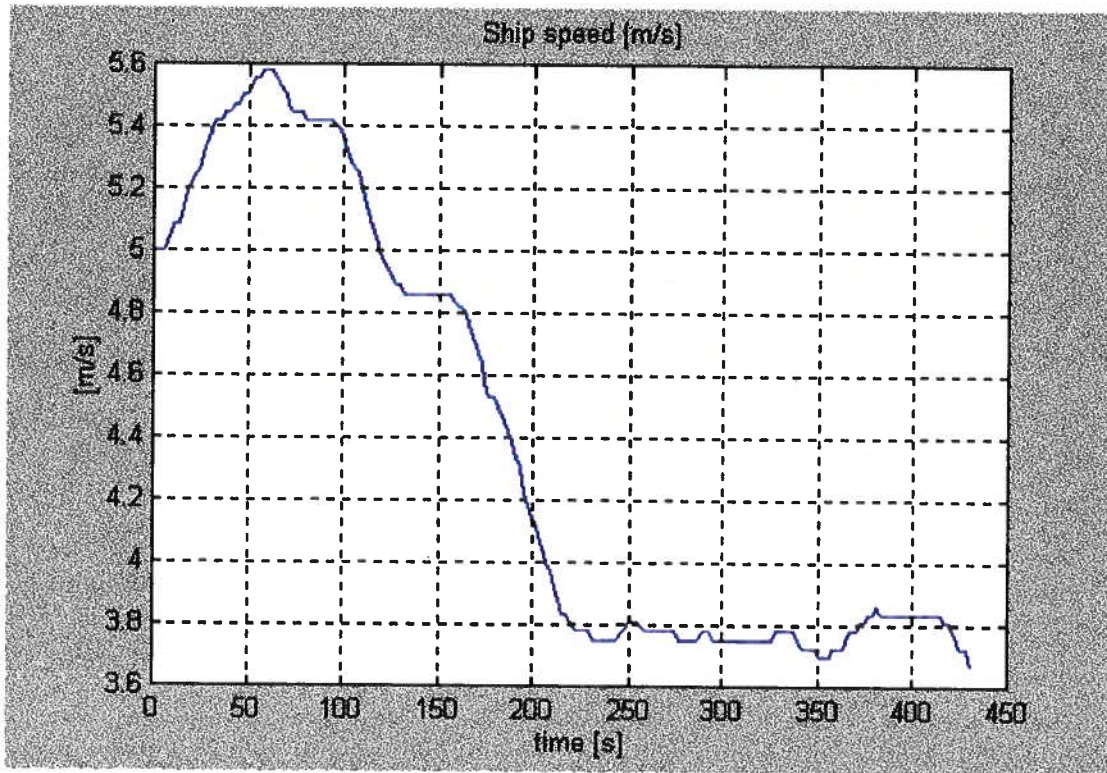
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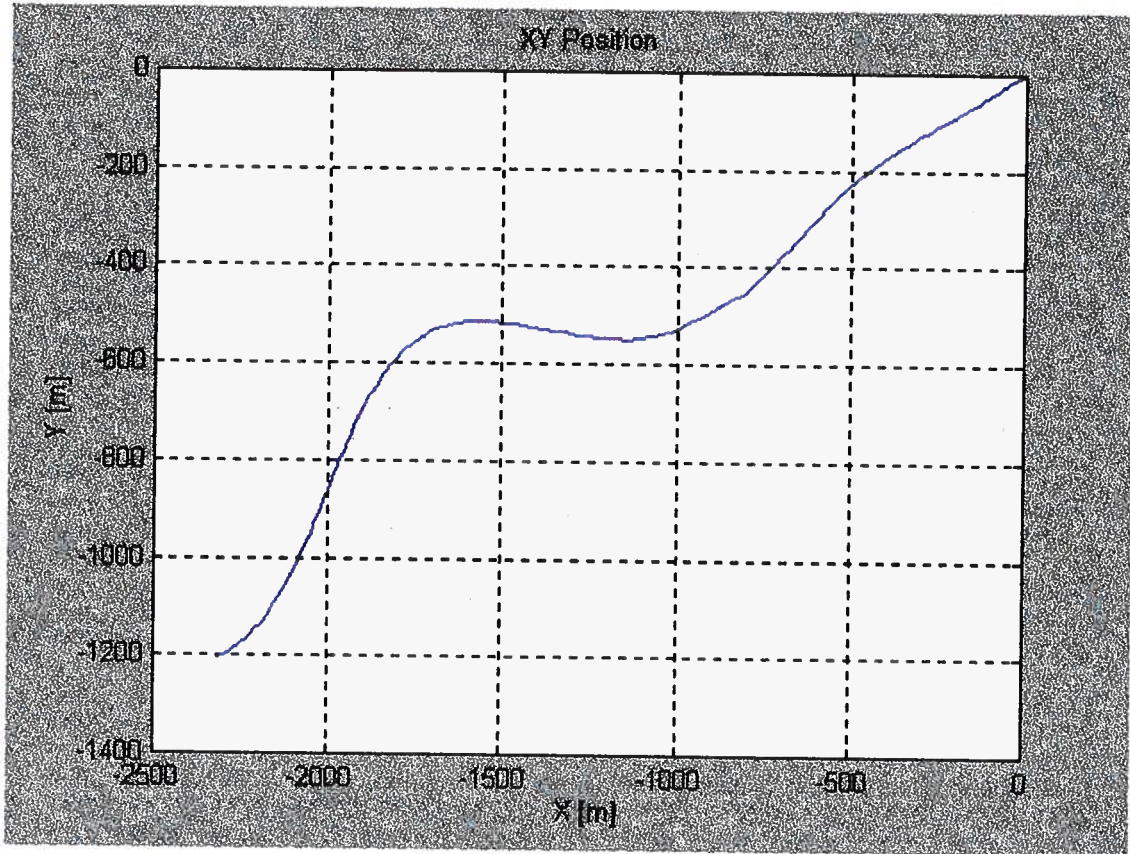
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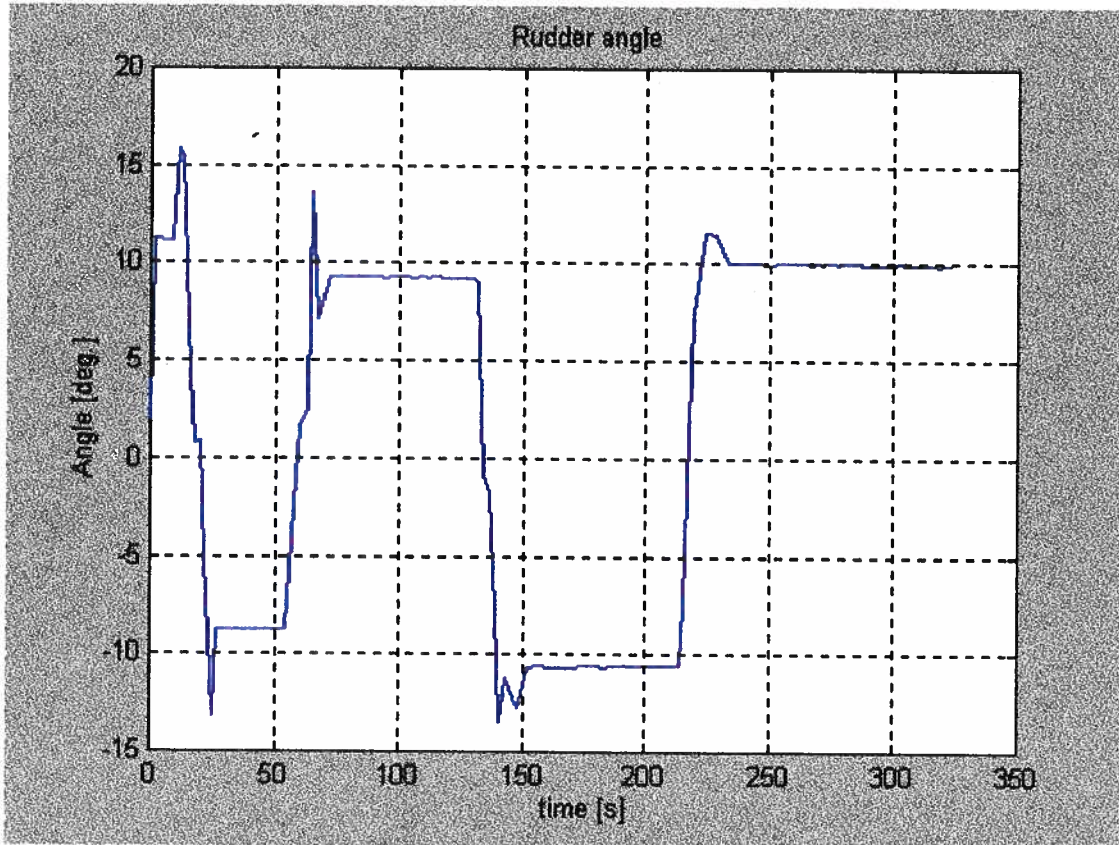
## **Appendix B**

### **Time Series of Zig-zags**

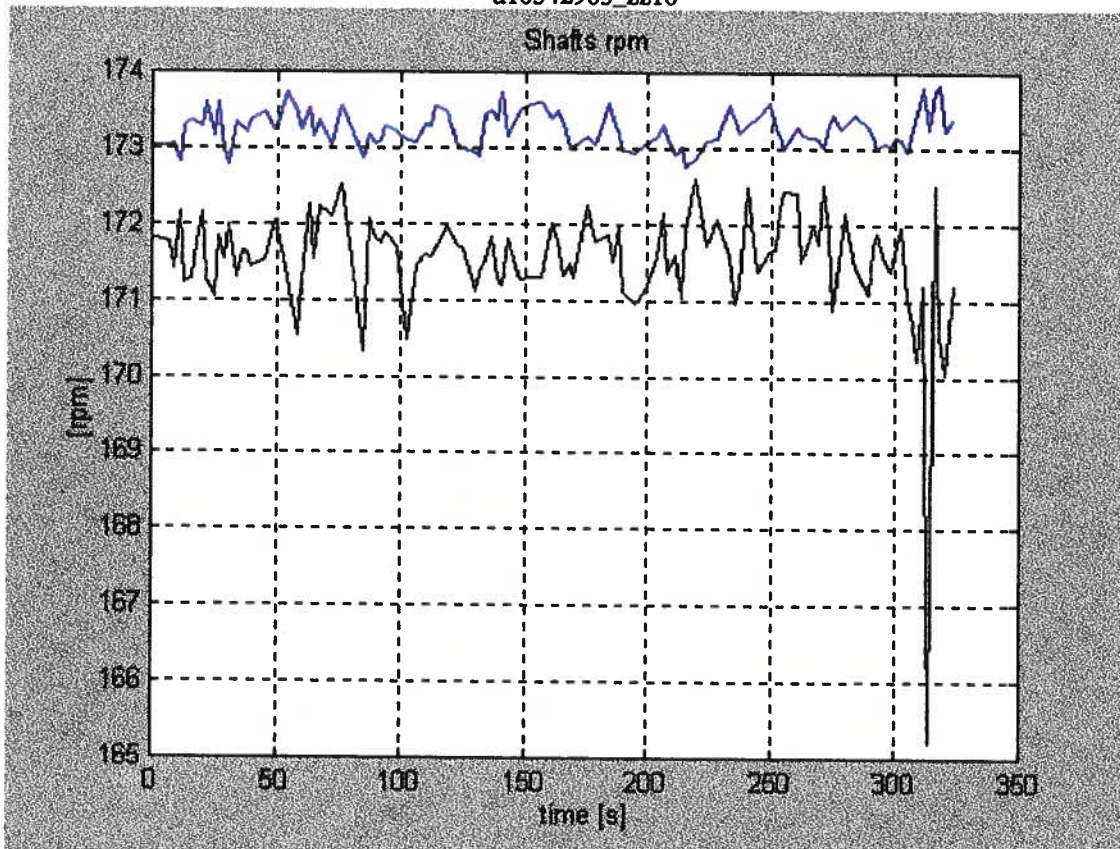
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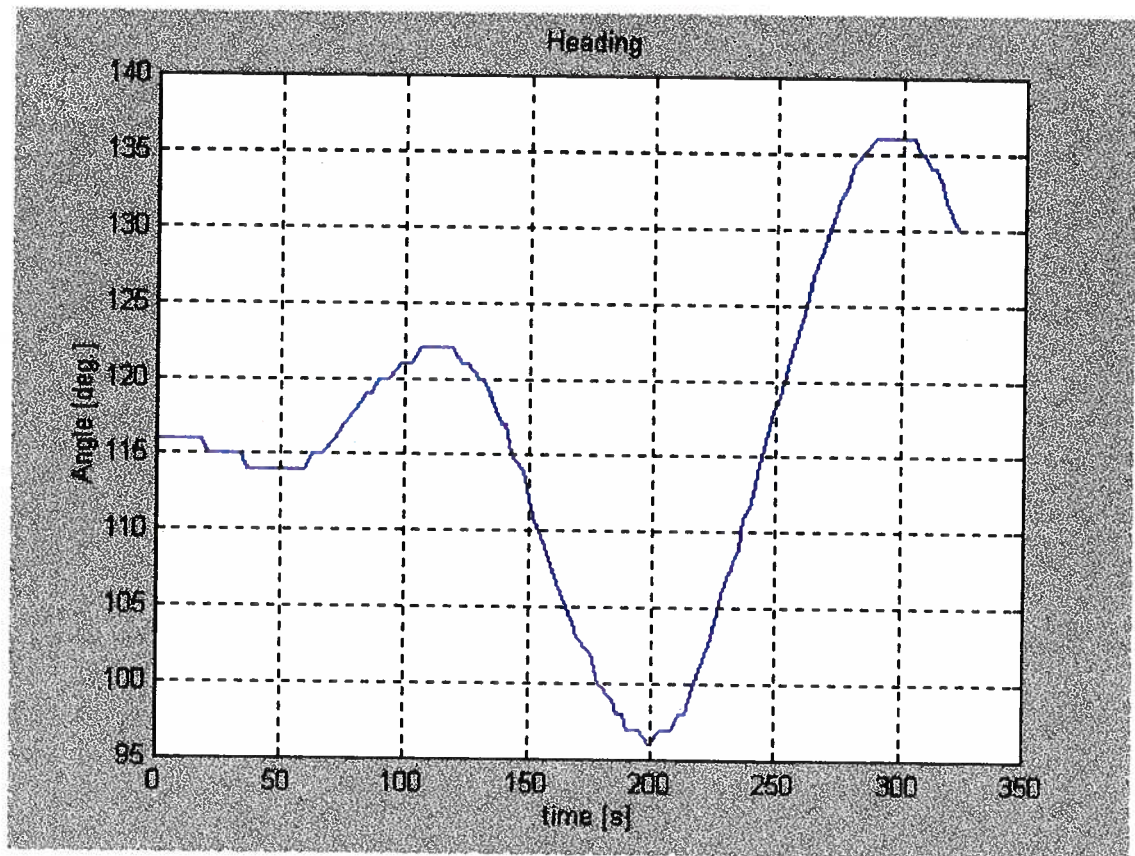
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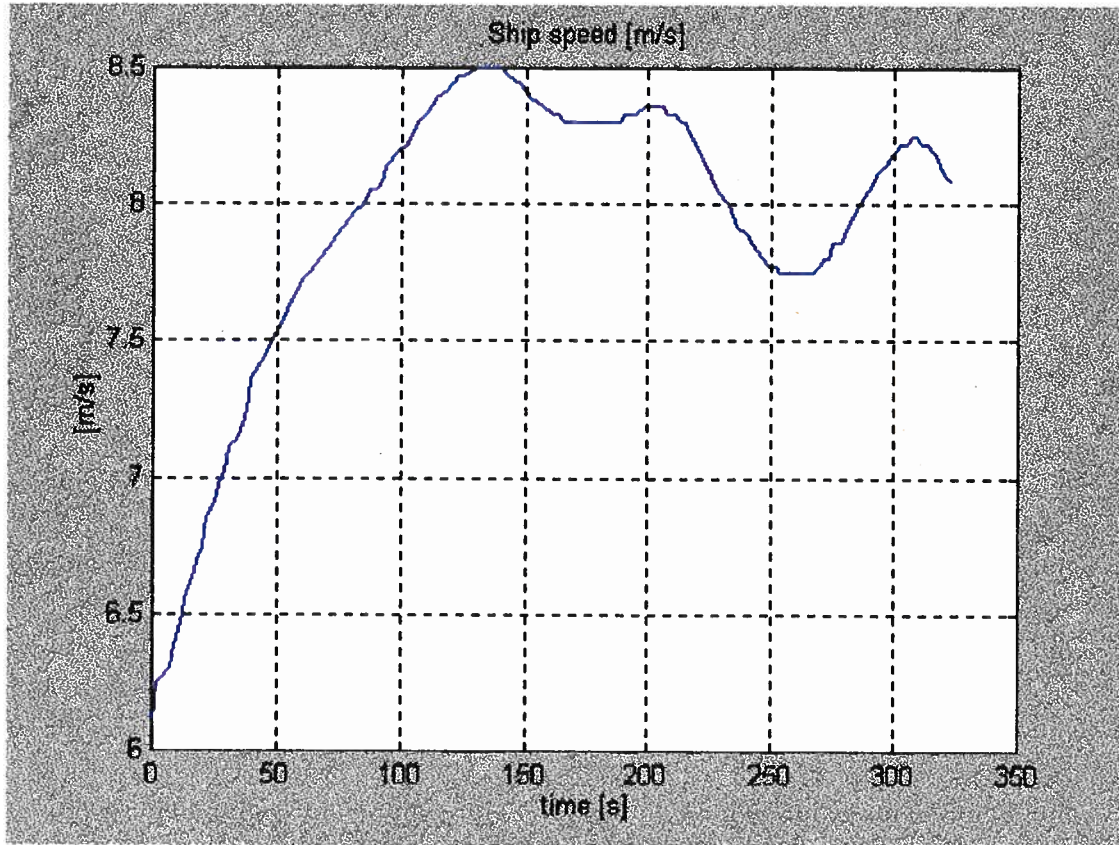
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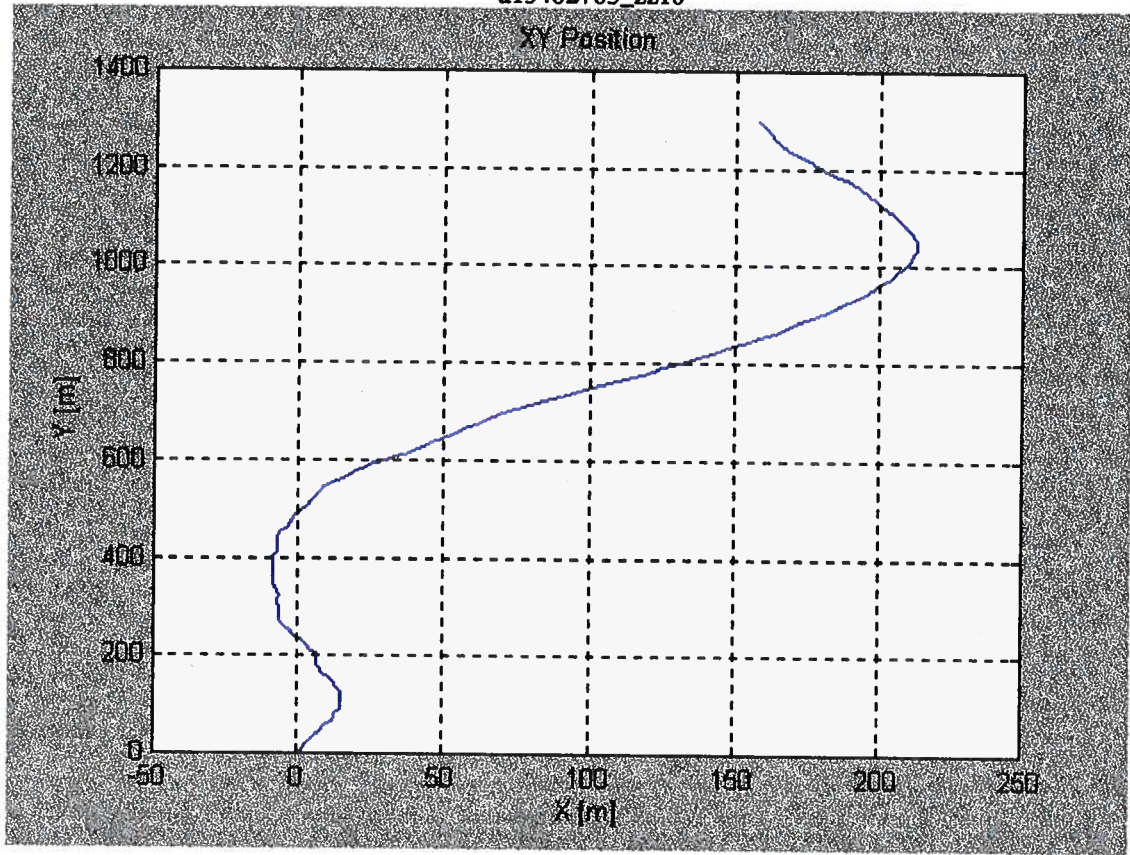
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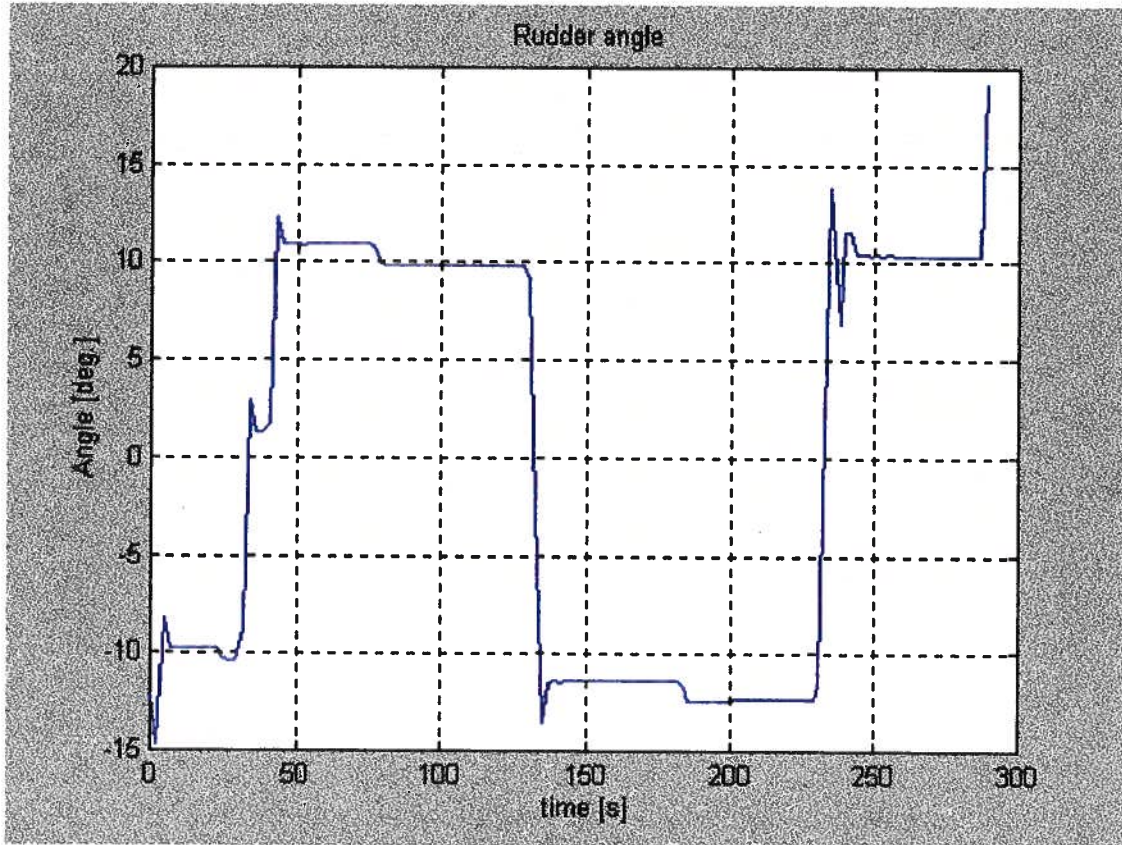
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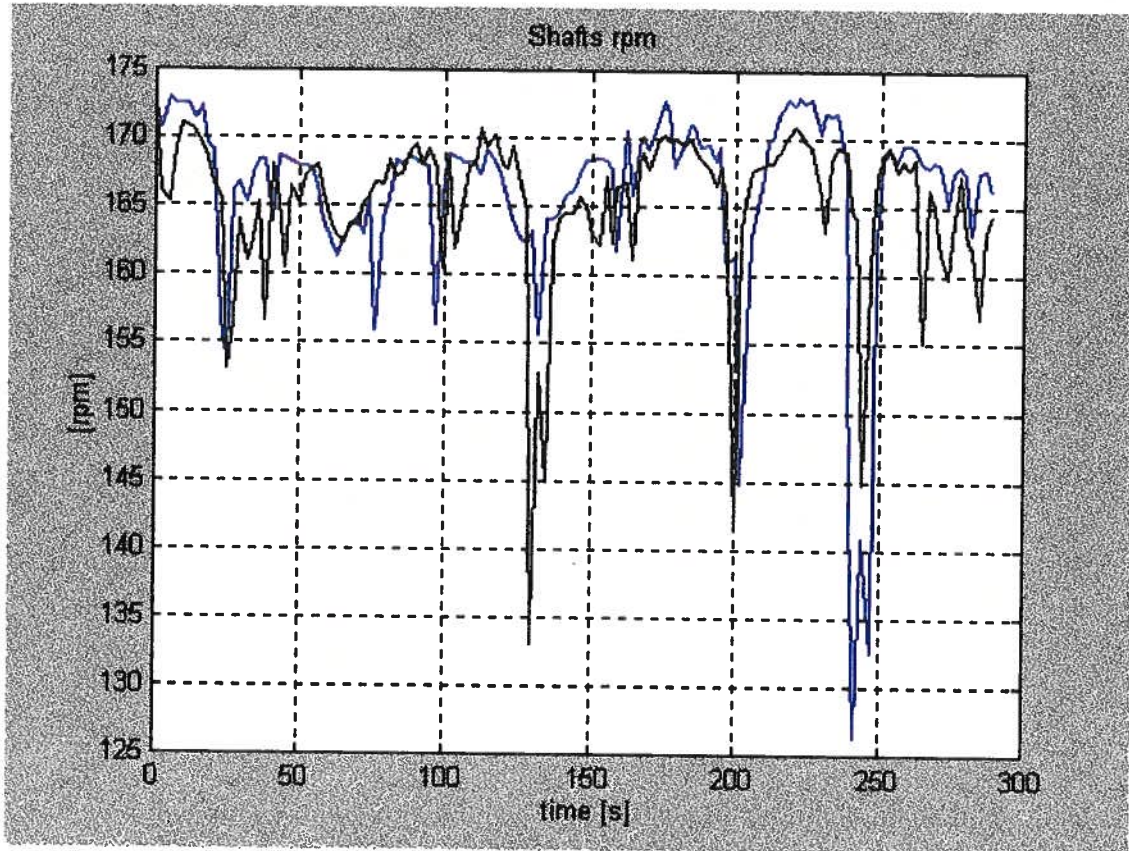
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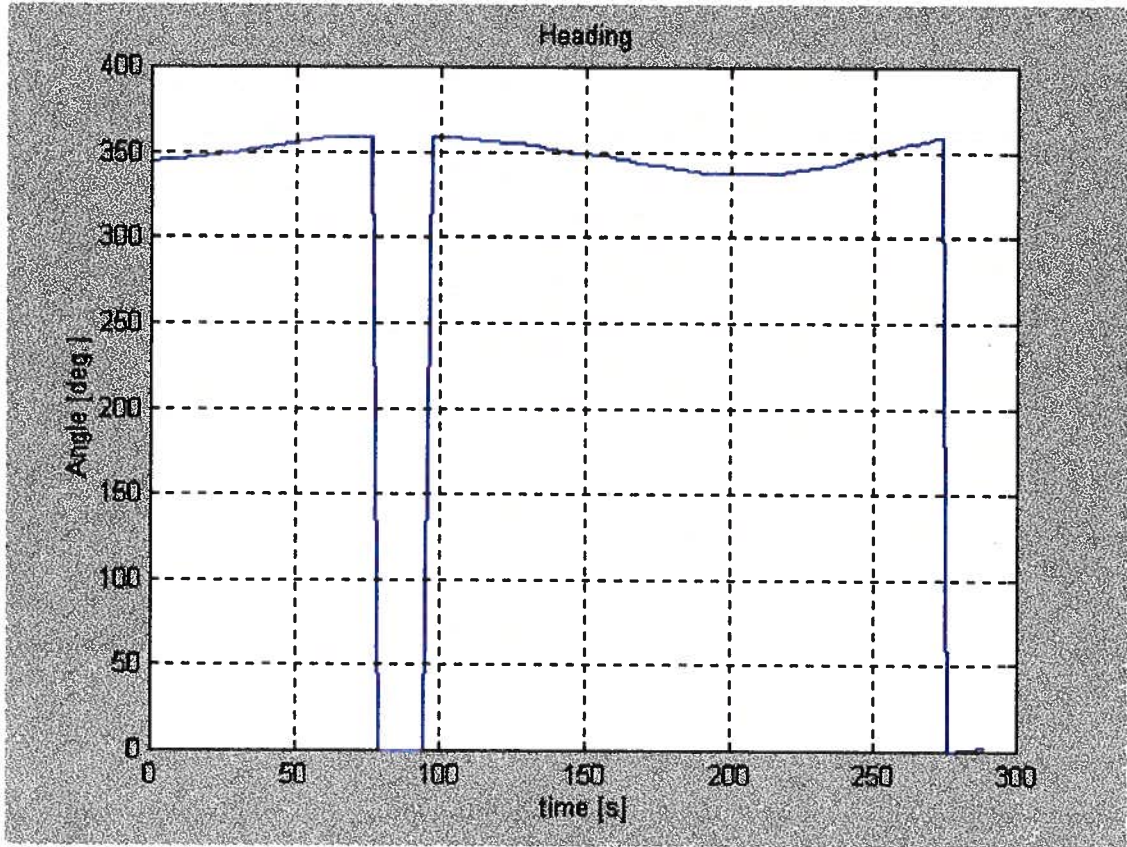
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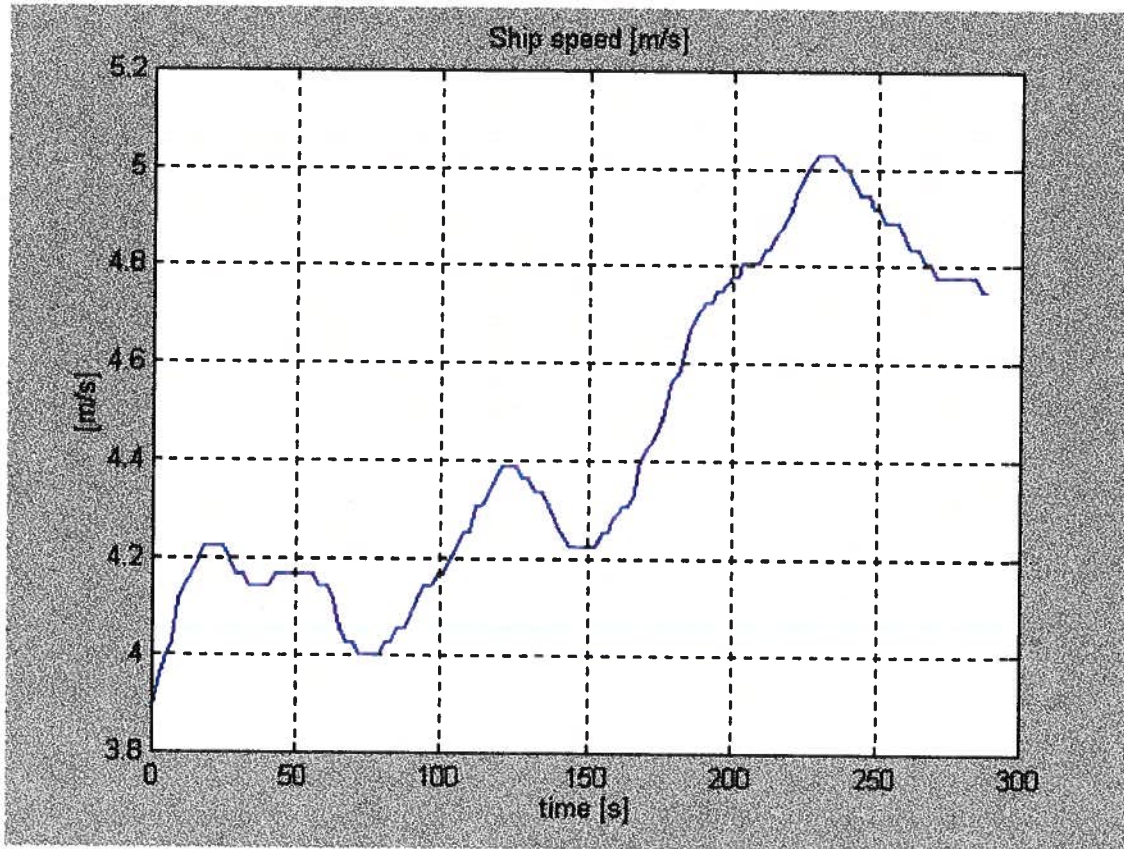
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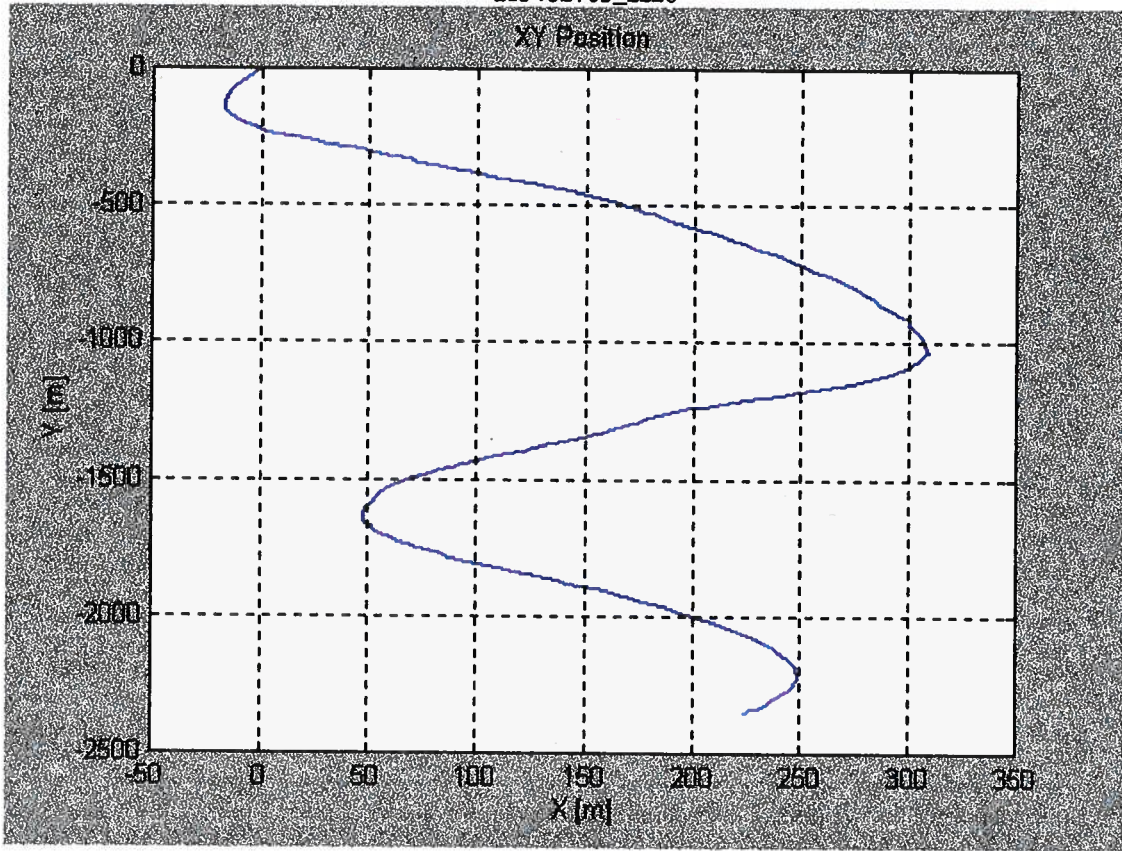
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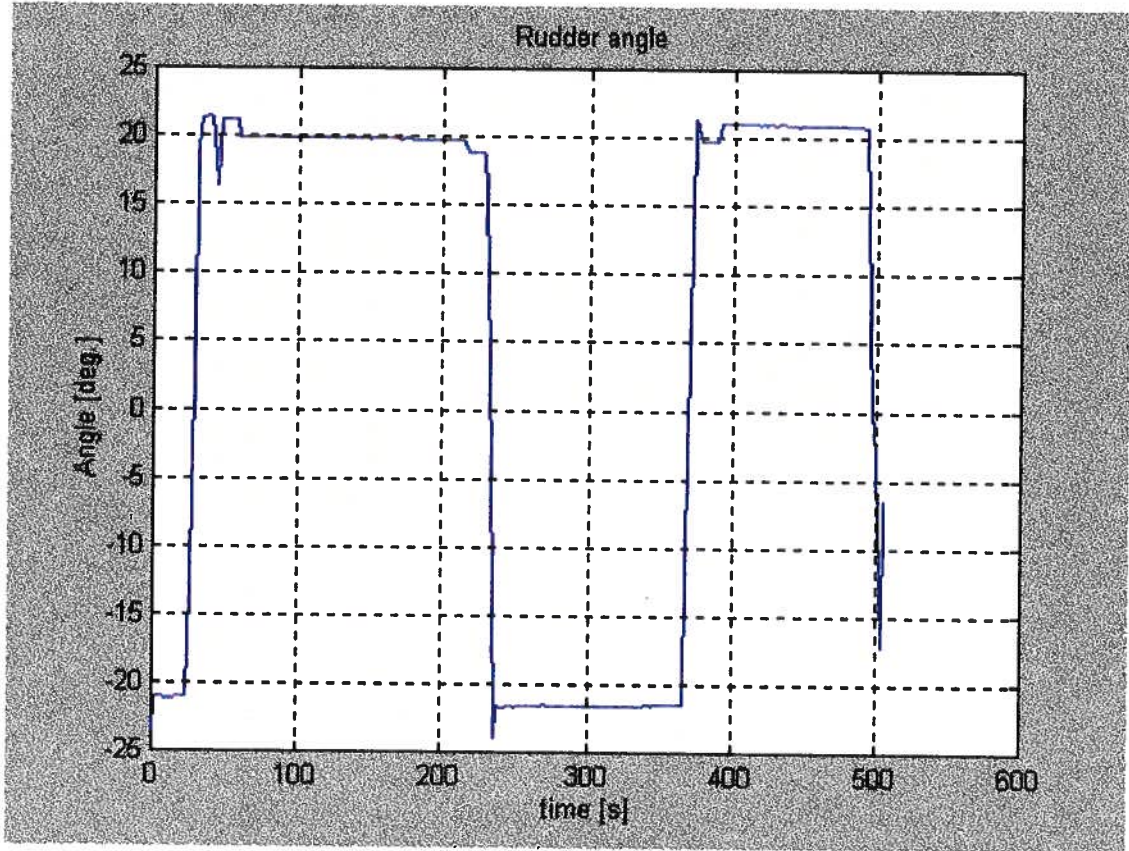
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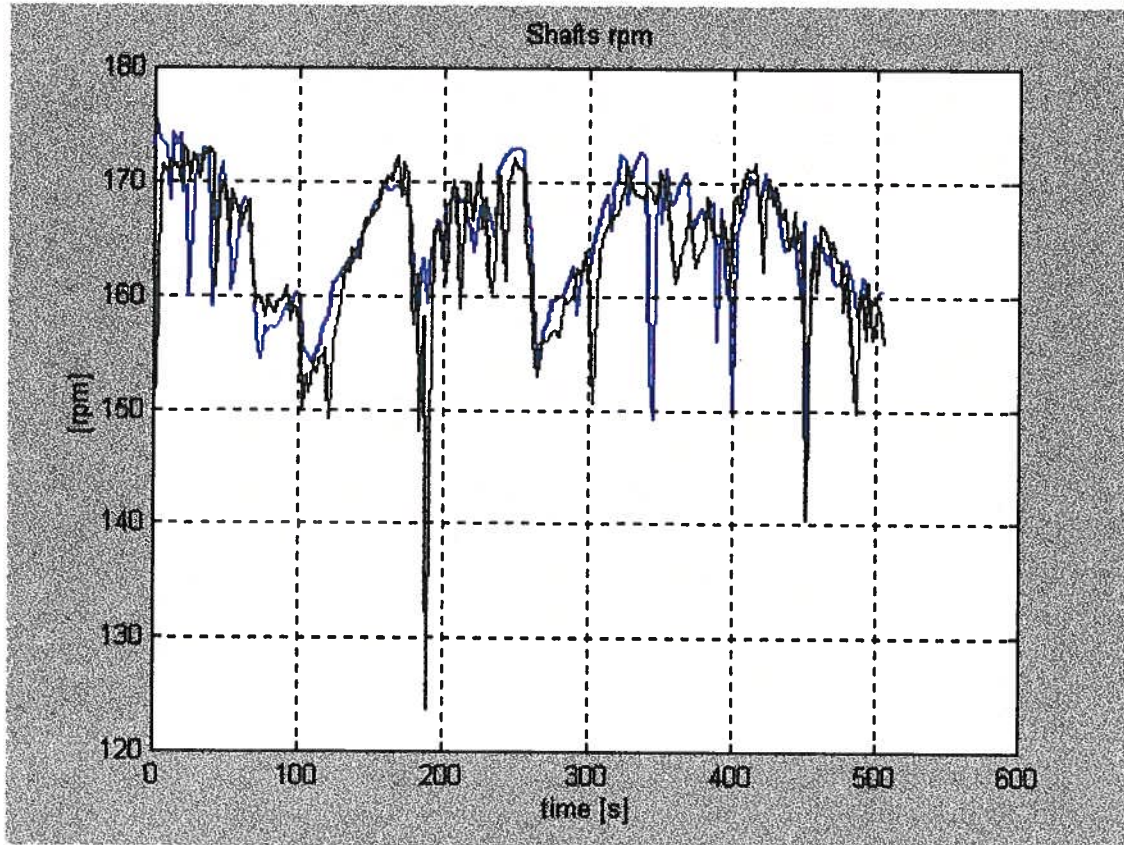
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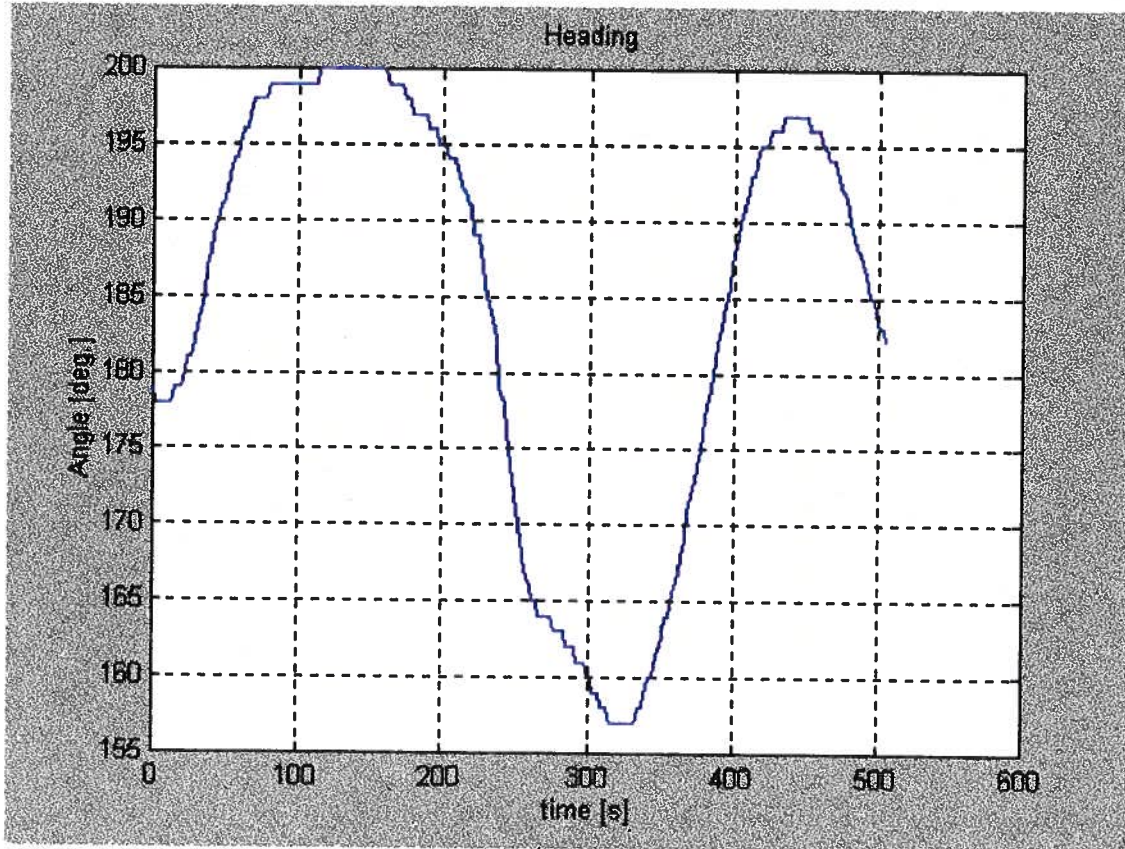
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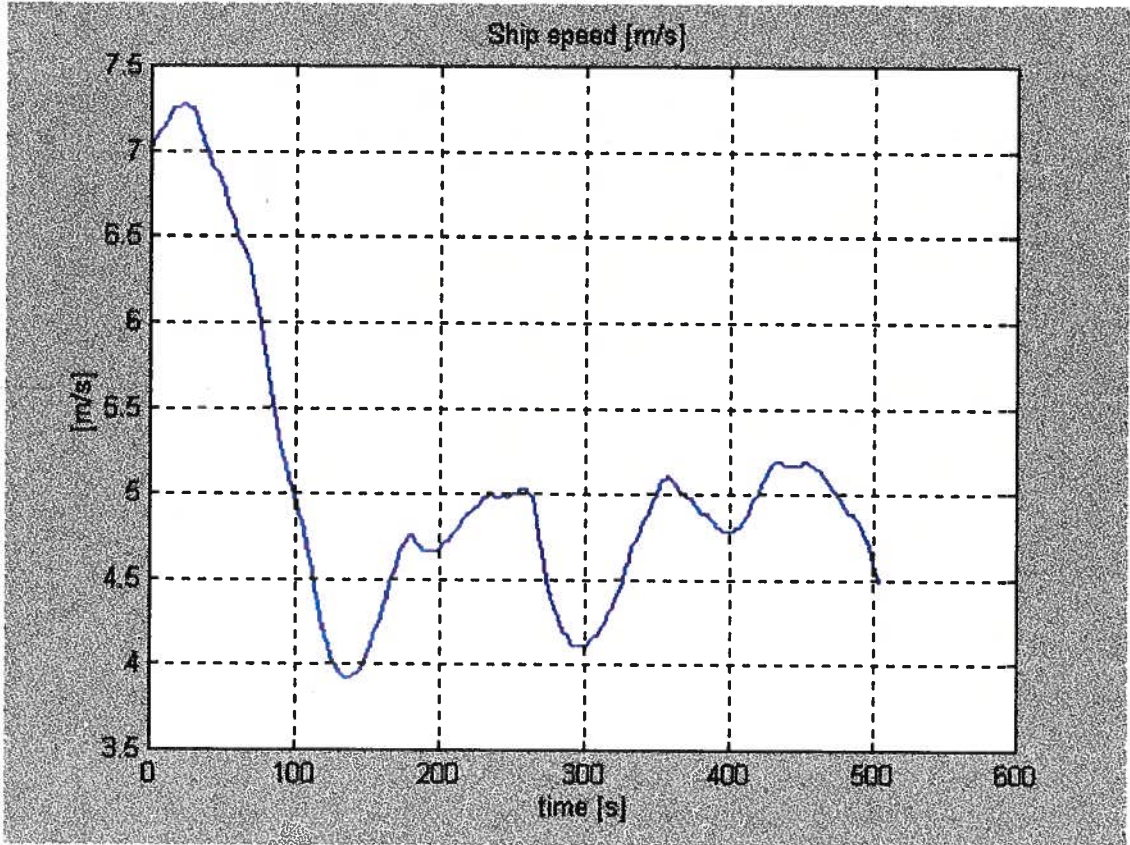
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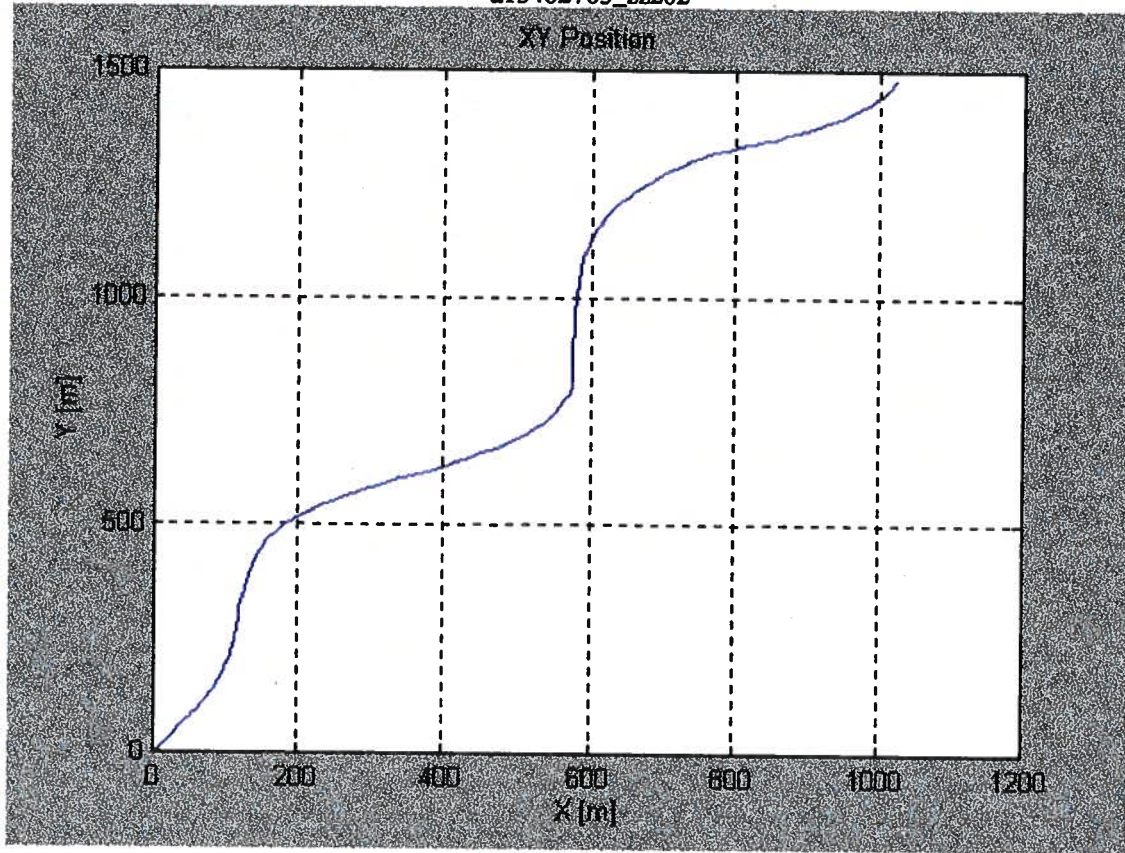
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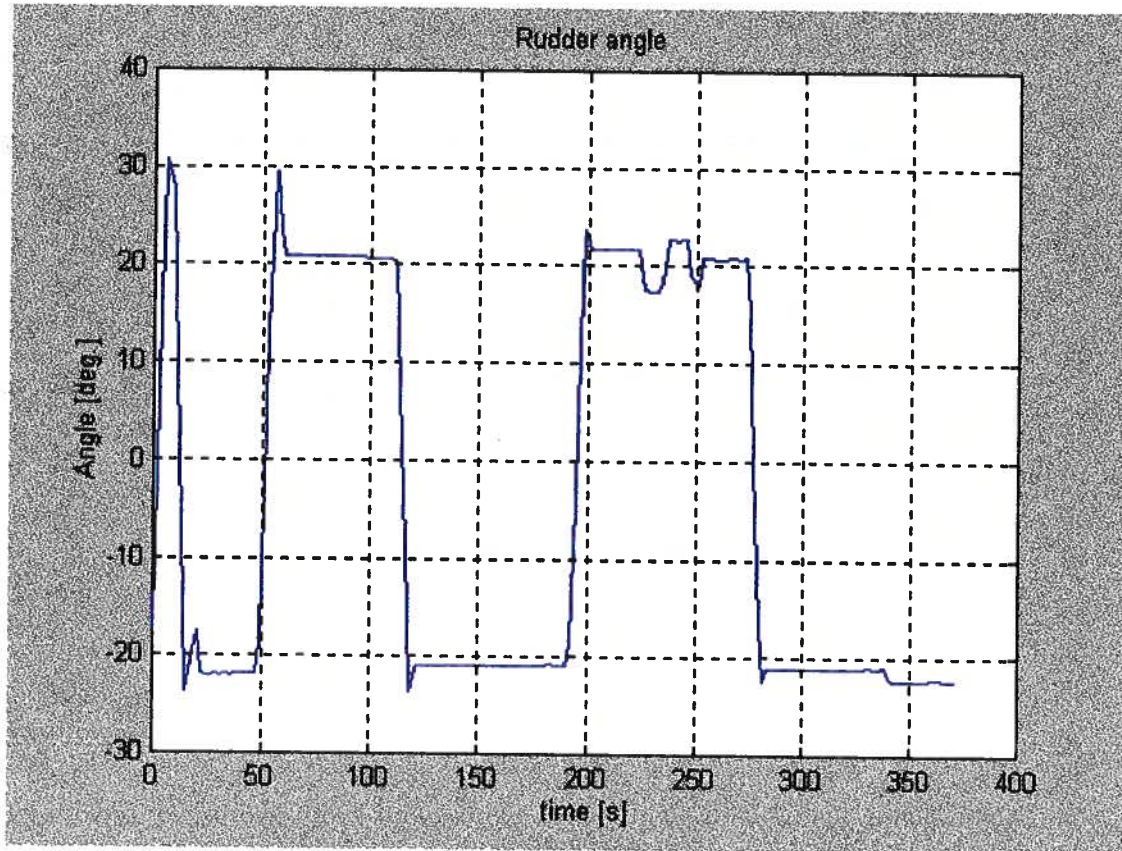
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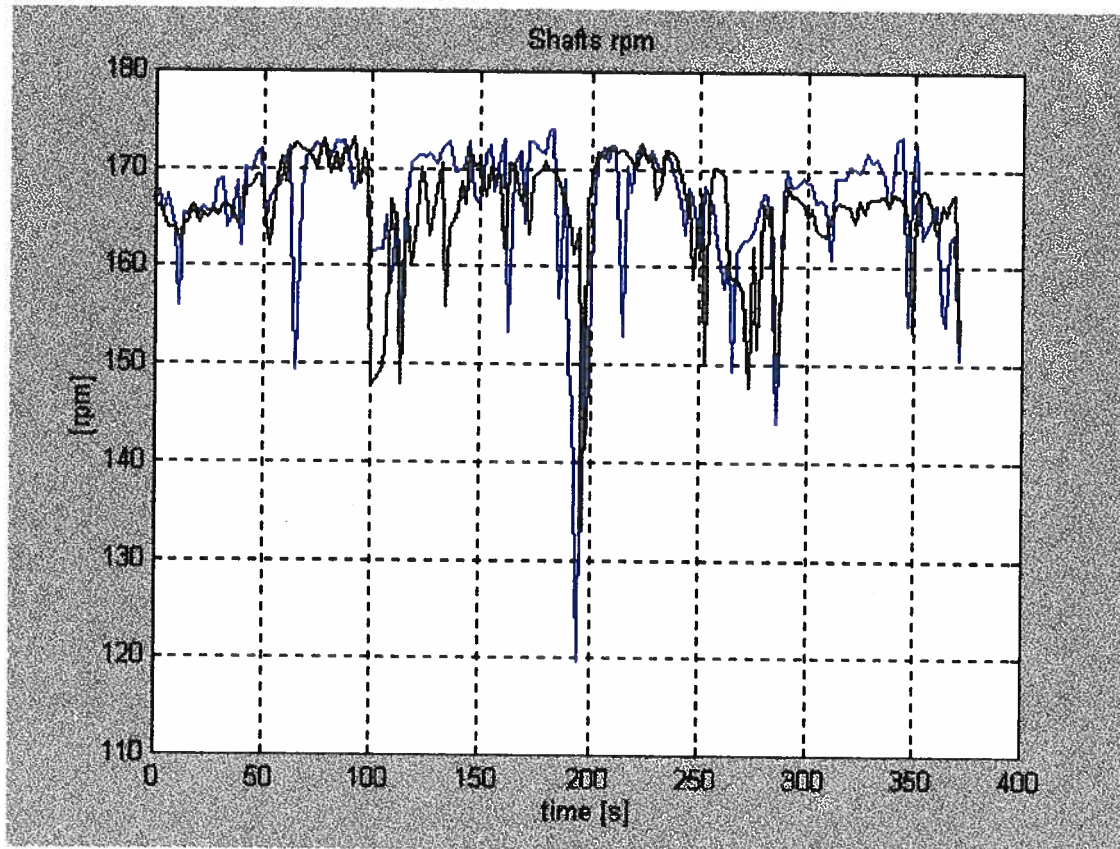
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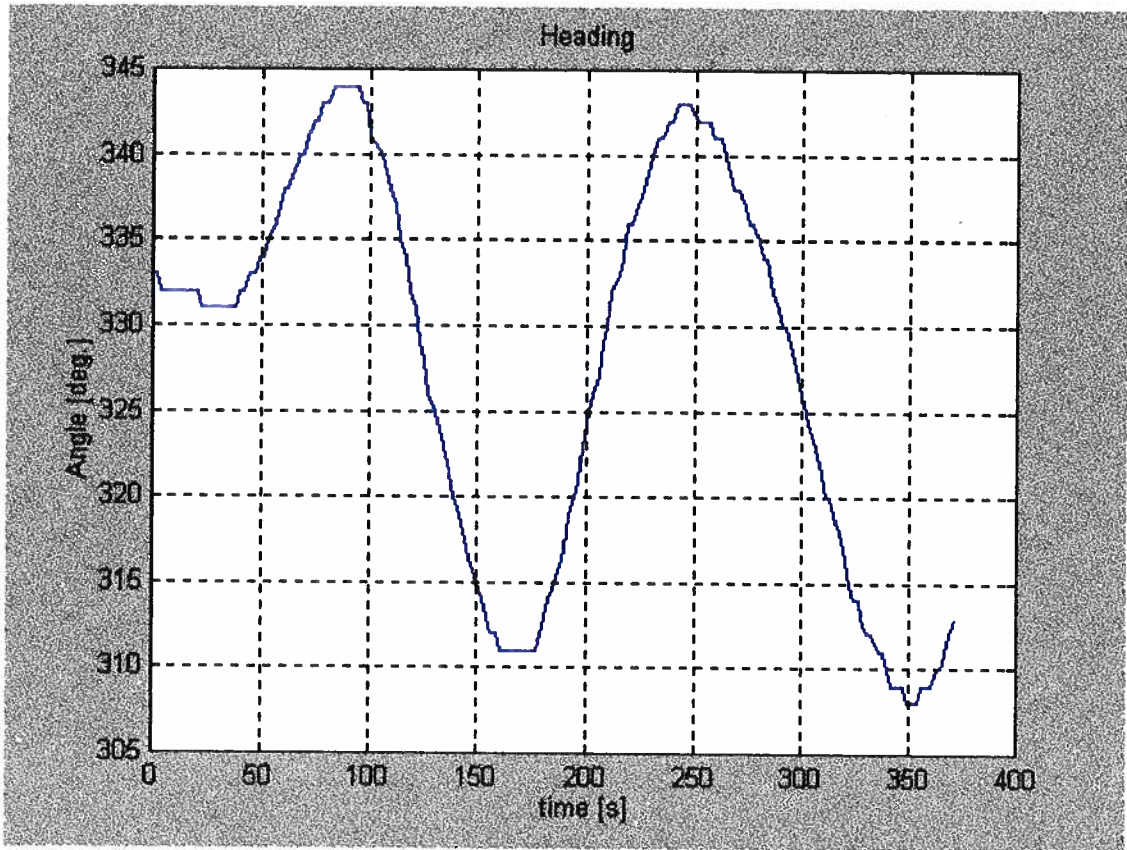
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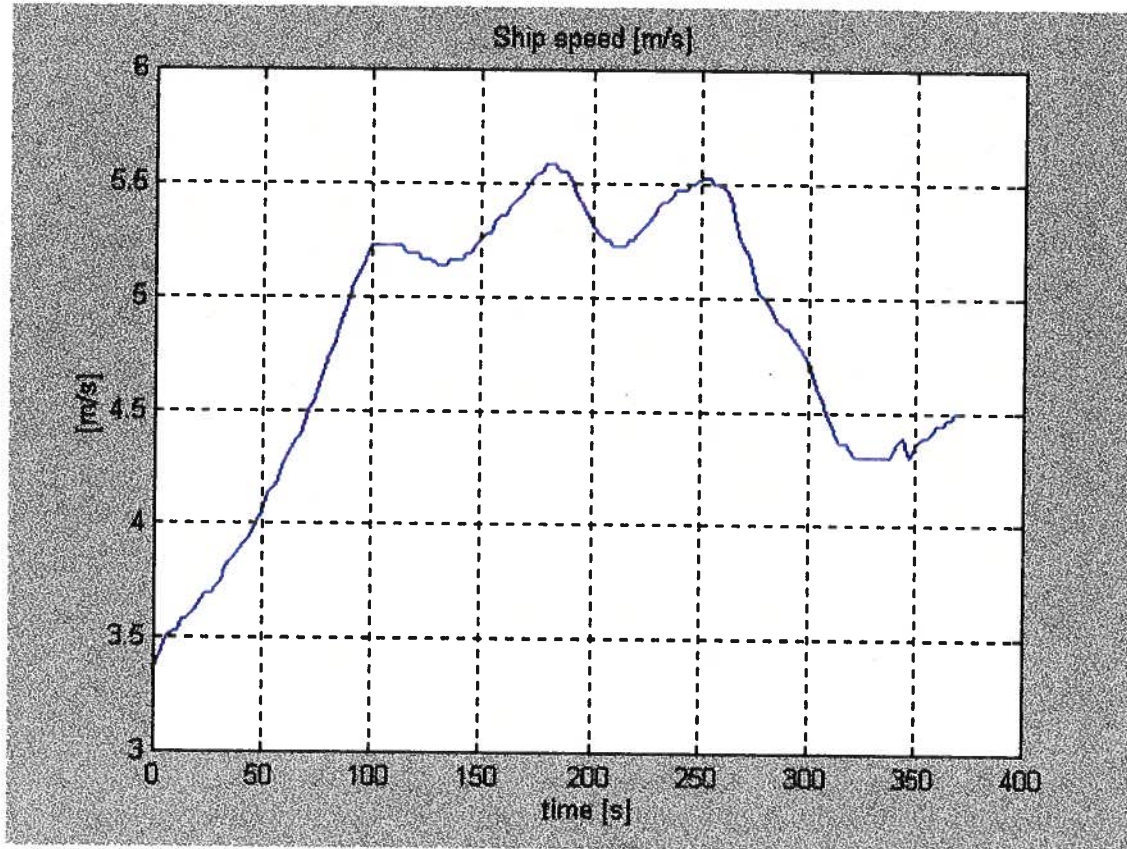
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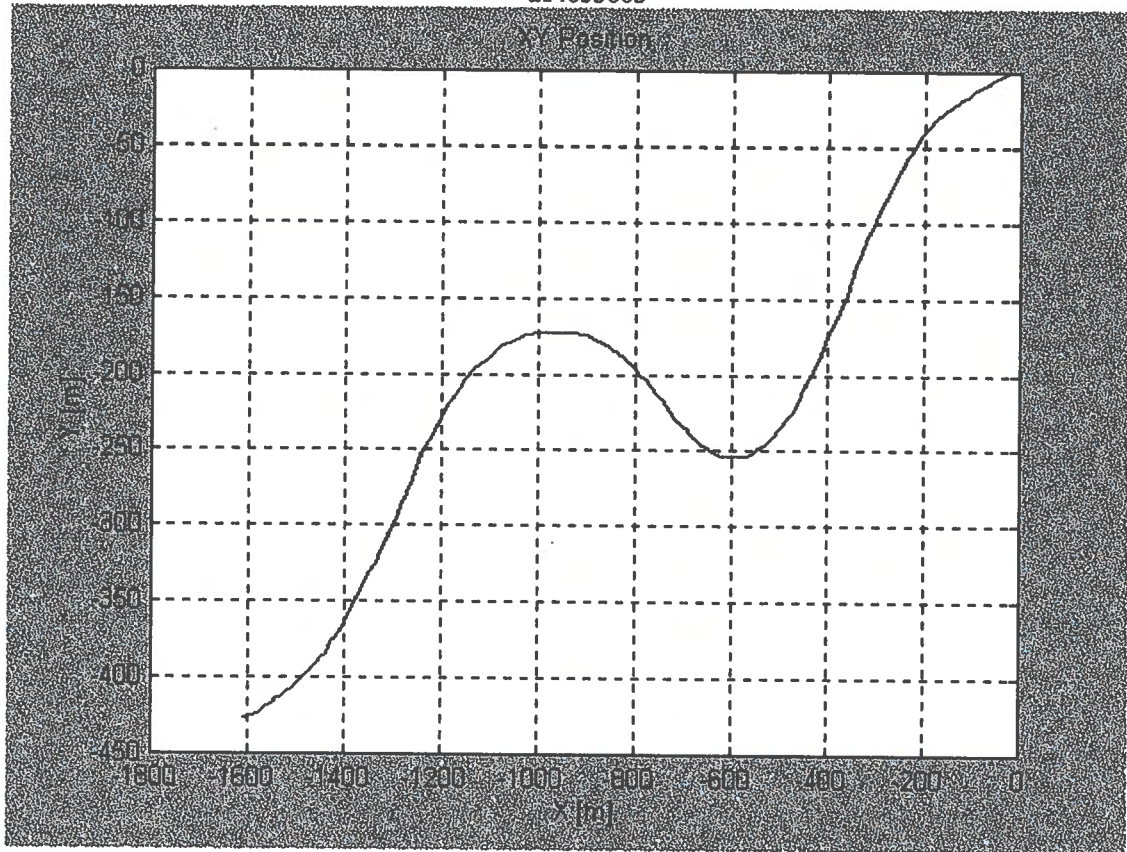
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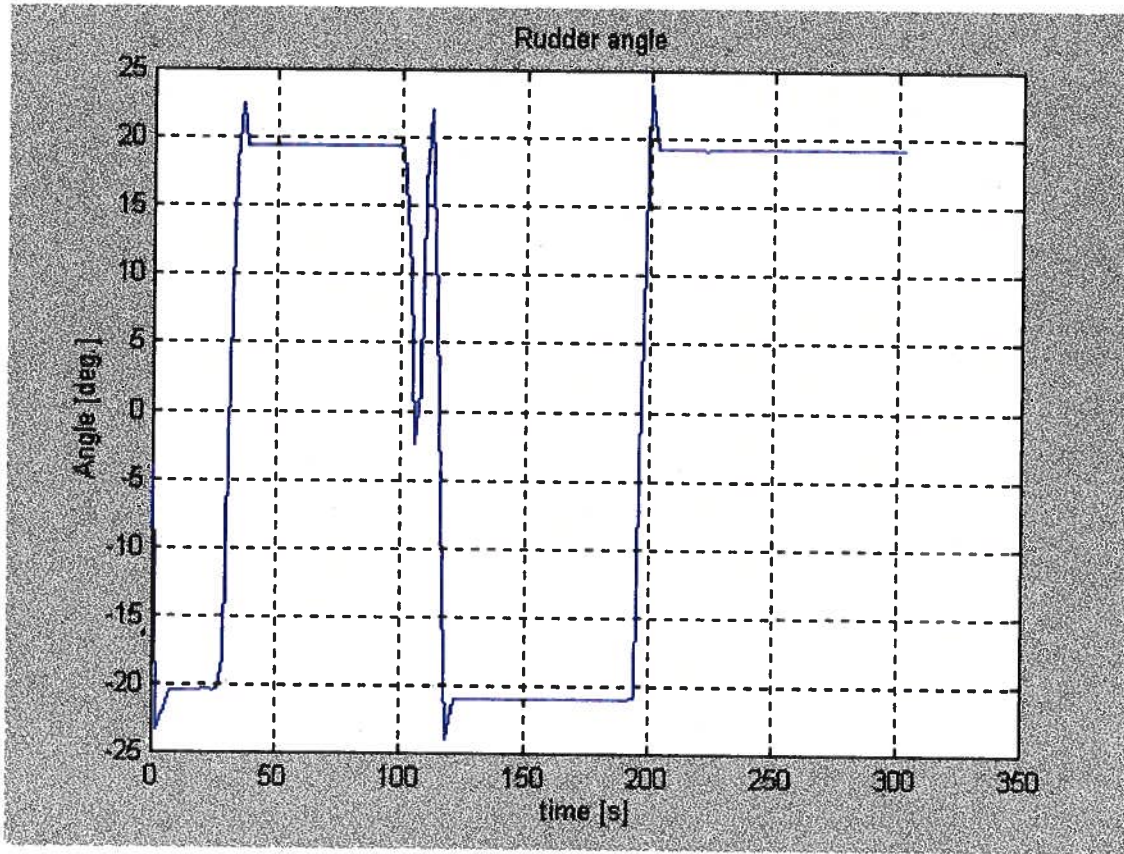
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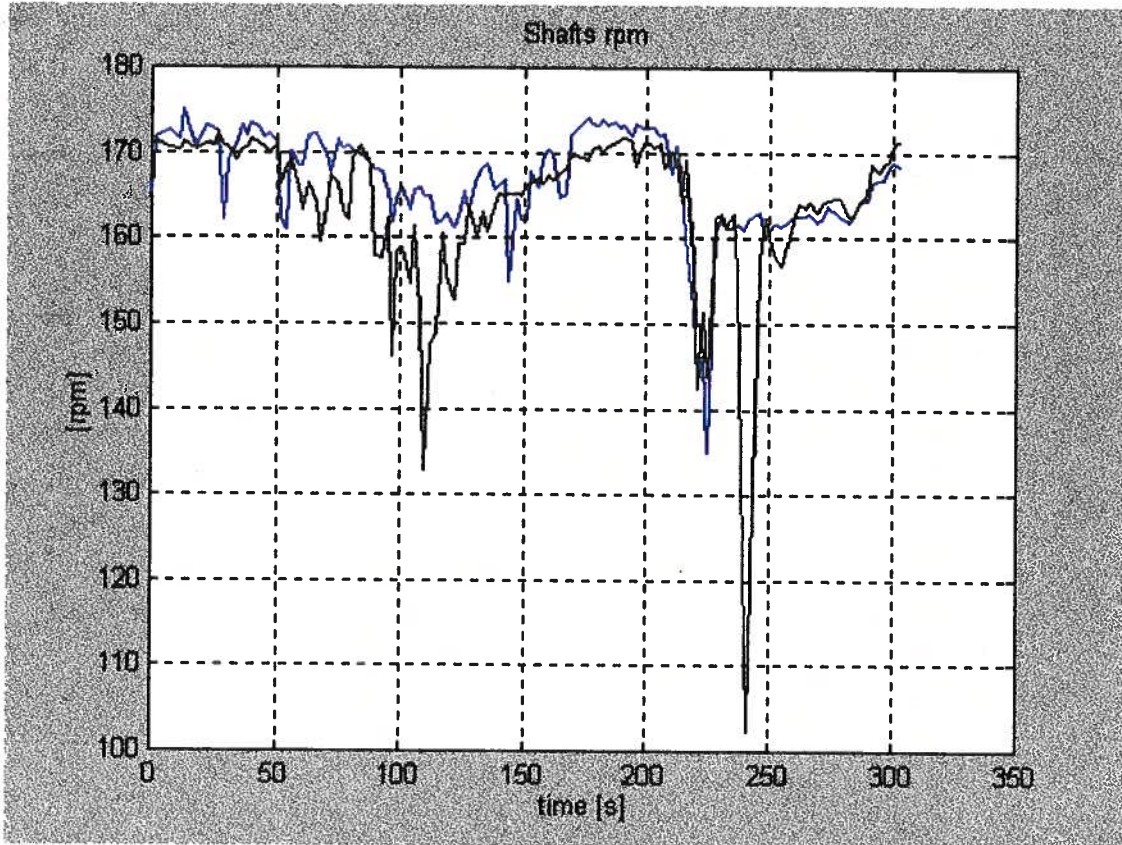
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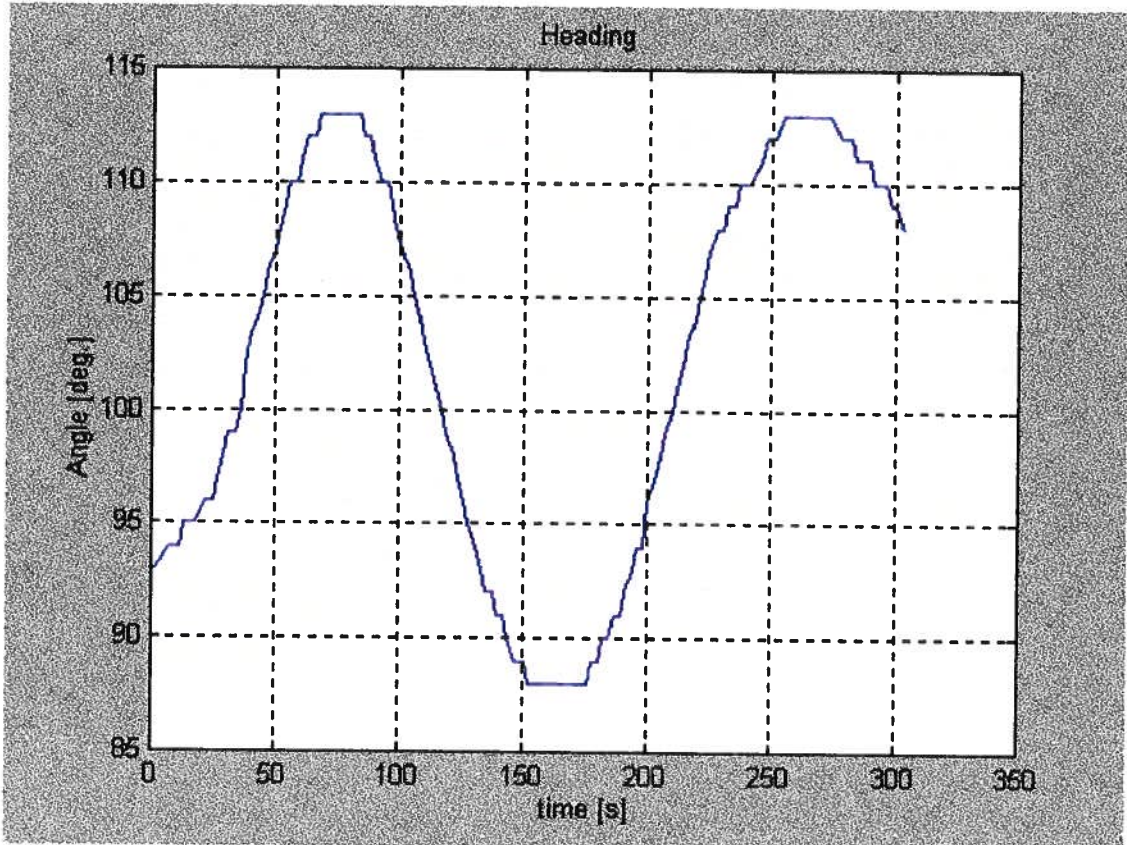
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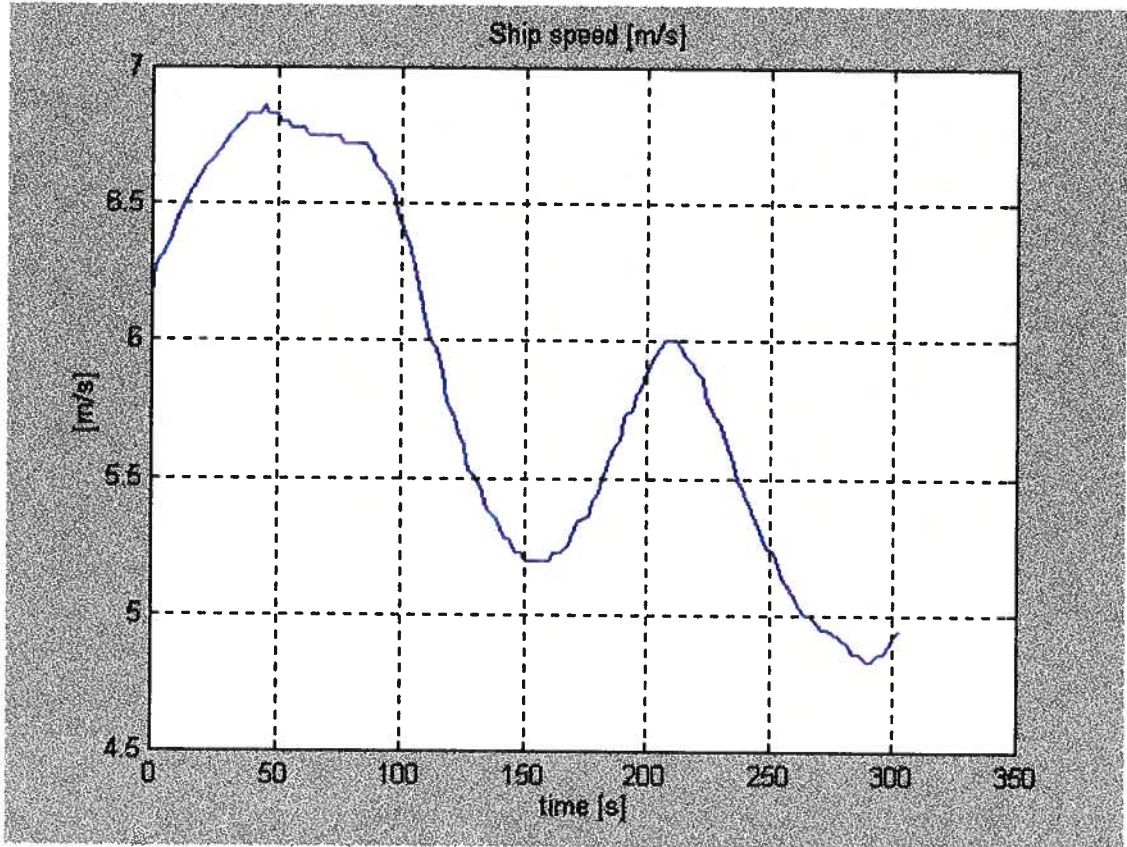
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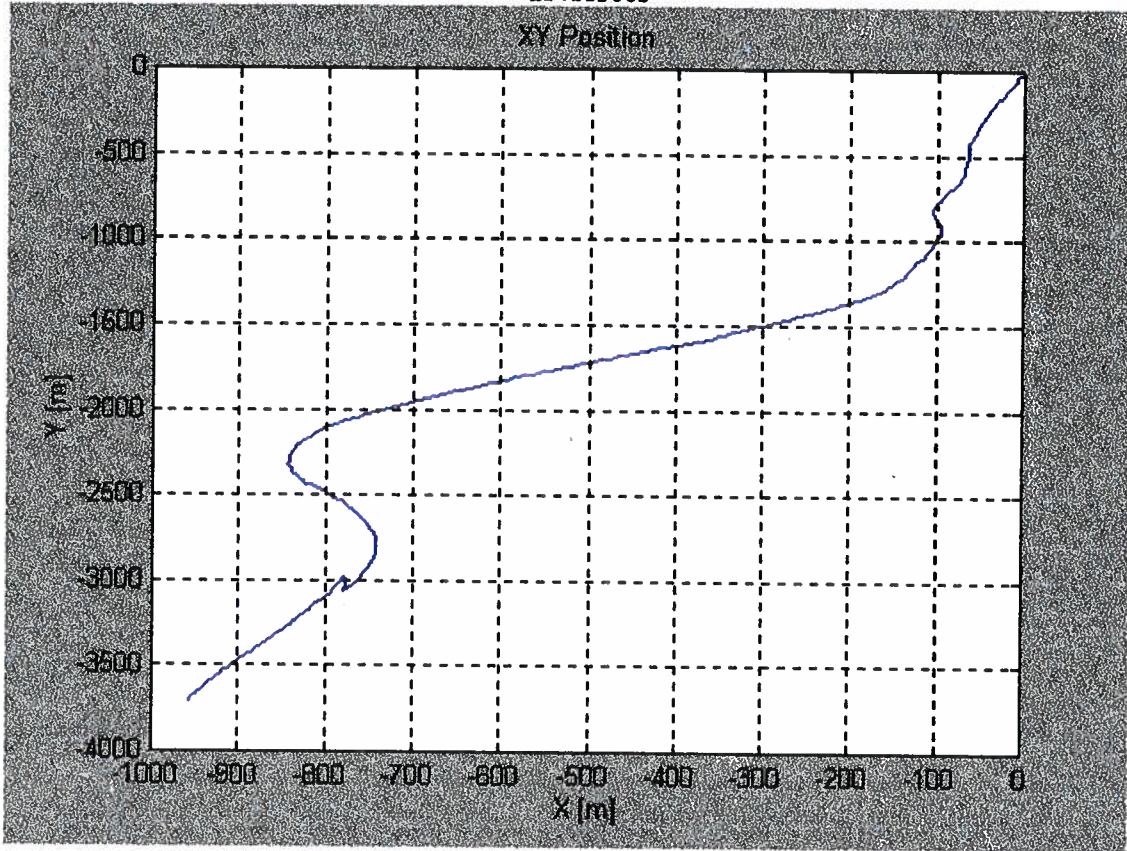
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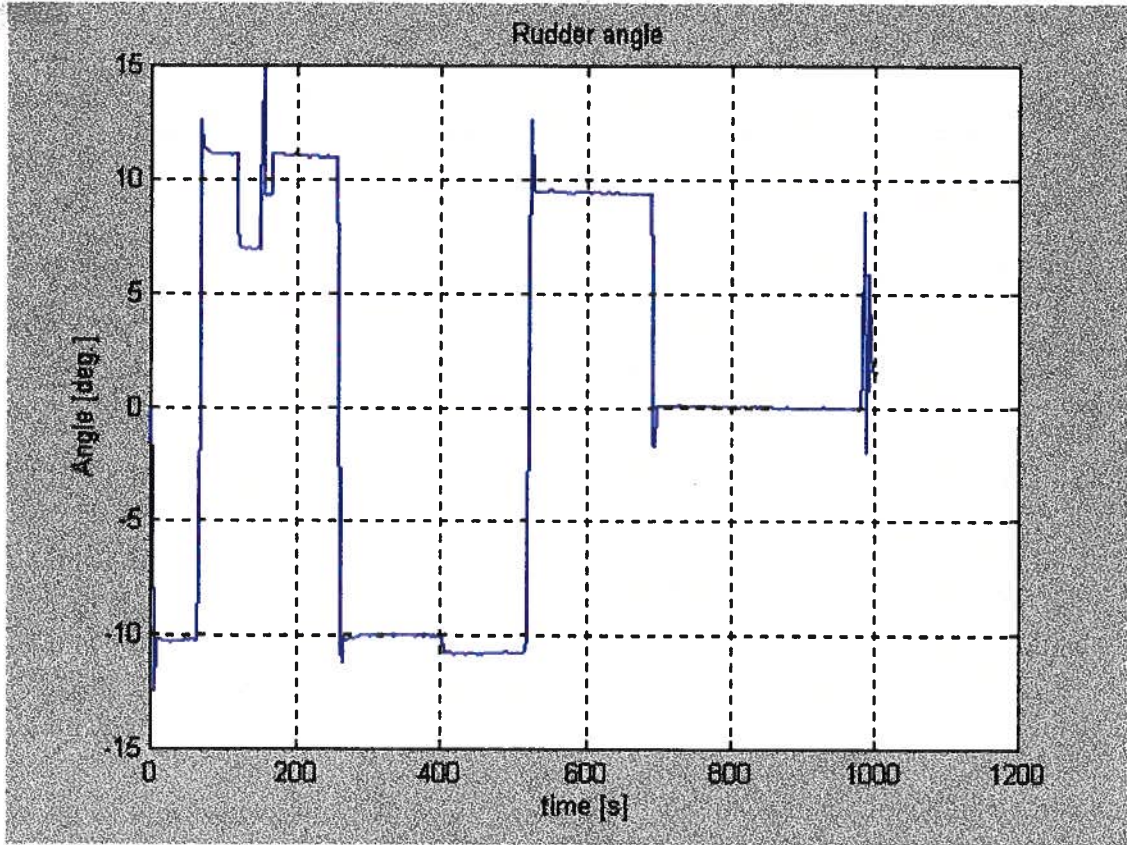
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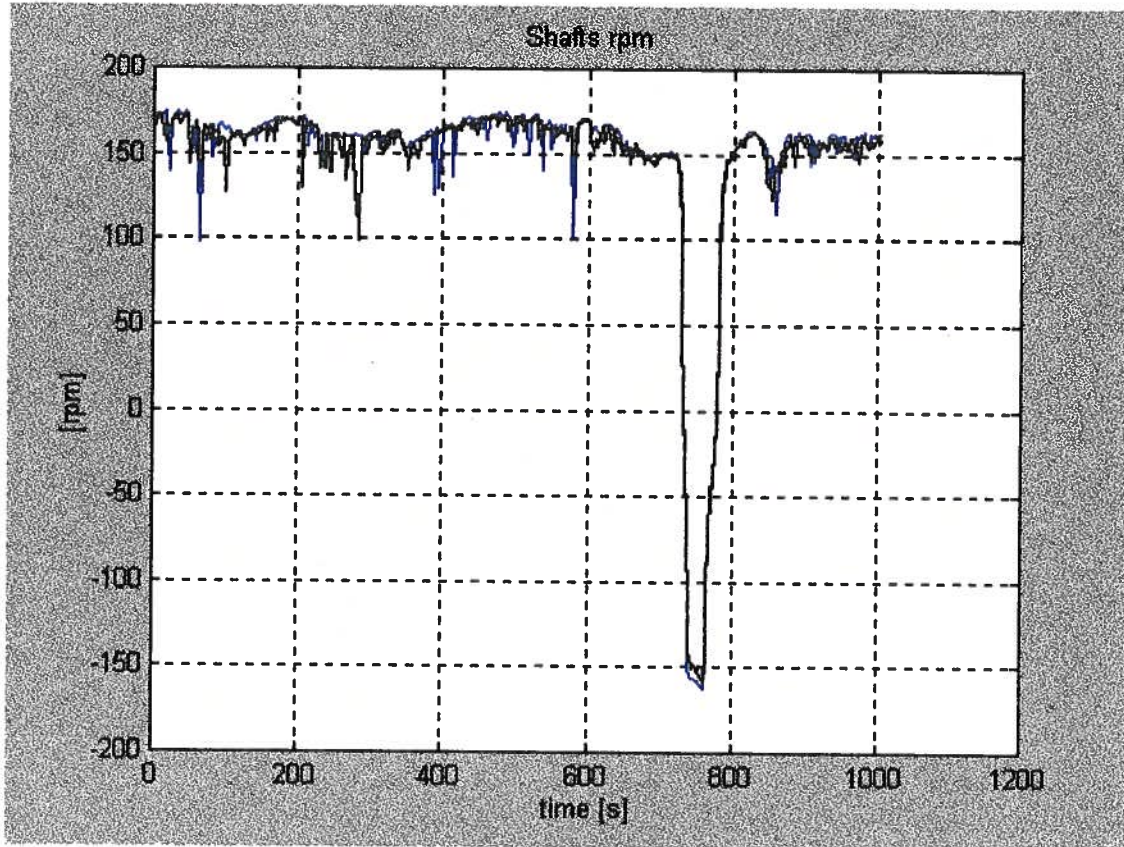
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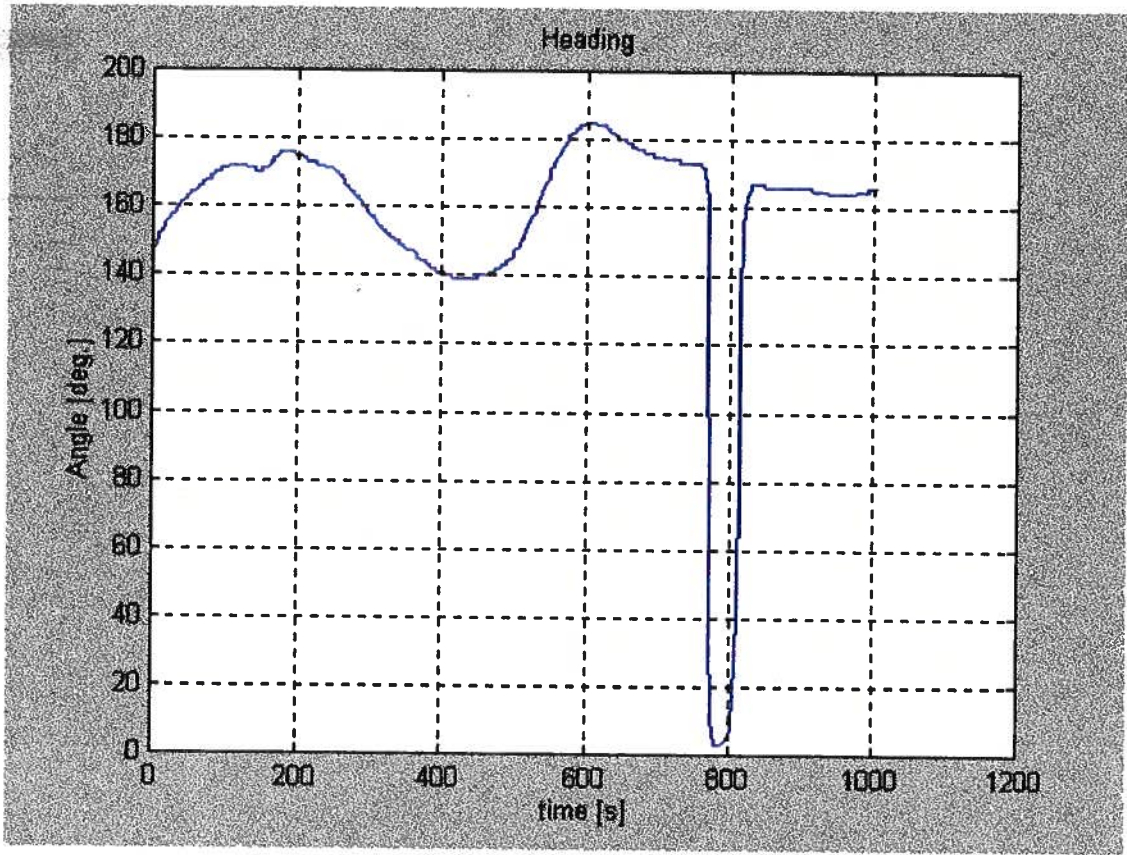
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