A ZIG-ZAG TEST ANALYZER

Analyse van één zig-zag (standaard) test.

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1. PREFACE: There are a number of procedures of analysing the zig-zag test to obtain the steering quality parameters of a ship in question, ranging from the simple method of the first-order (K and T) equation to the phase plane analysis taking the higher order parameters and non-linearity into account.

In spite of the great developments in the PMM experiment plus digital simulation technique, this sort of analysis will keep its important role, in the writer's view, for the time being.

At least in the analysis of actual ship trials we have to rely on it. Many model basins are, at the same time, still making a good deal of free-running model experiments as a quick means of evaluating a hull and/or rudder configurations.

The basic principle of the analysis now in consideration is to define a number of parameters of a mathematical model so that the model fit with a detected ship motion and rudder movement as closely as possible. This may lead us to a simple simultaneous equations or some kind of the least square error method or iteration procedure.

A difficulty arising at this point is that the more the number of parameters to be defined, the more complicated the computation and the more error is liable to be introduced.

Here is another idea. To make the iteration on an analogue computer; adjust the parameters of the mathematical model built in the computer merely by turning a number of knobs and keep one eye to the phase plane trajectory displayed on a cathode-ray oscilloscope. This note describes a device of this principle and some of the results obtained.

2. MATHEMATICAL MODEL AND BASIC SCHEME OF ANALYZER: The mathematical models employed are:

for a ship response

$$\left.\begin{aligned} T_1T_2\dddot{\psi} + (T_1+T_2)\ddot{\psi} + \dot{\psi} + \alpha\dot{\psi}^3 &= K\delta + KT_3\dot{\delta} \\ \delta &= \delta_m + \delta_r \end{aligned}\right\} \quad (1)$$

where δ_m : measured (nominal) rudder angle
δ_r : residual rudder angle

and for a steering gear,

$$\left.\begin{aligned} T_E\dot{\delta}_m + \delta_m &= \delta_m^* && \text{when } \delta_m^* - \delta_m \leq 6^\circ \\ T_E\dot{\delta}_m &= 6 && \phantom{\text{when }} \delta_m^* - \delta_m \geq 6^\circ \end{aligned}\right\} \quad (2)$$

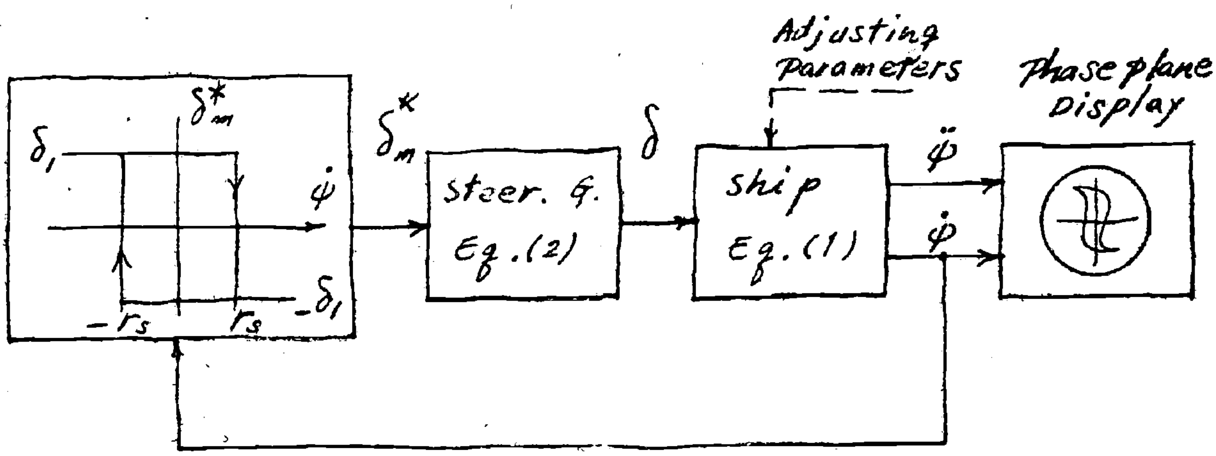
where δ_m^* denotes the command rudder angle (nominal).
(2) implies a first-order lag (exponetial lag) with speed satura-

tion, which is the character of electro-hydraulic gears now in common use.

It is possible to produce a certain sequence of rudder command, which follows the rudder command recorded at the test. Then we will get a $\ddot{\psi} - \dot{\psi}$ phase plane trajectory displayed on the oscillo-scope, $\ddot{\psi}$ and $\dot{\psi}$ signals being fed out from the circuit simulating Eq. (1). Repeating the rudder command sequence signal at a reasonably high frequency (the time scale in the simulation should have been adjusted so as to fit this operation), the trajectory remains bright on the display. Then we could adjust the parameters of Eq. (1) by turning appropriate potentiometers so that the displayed trajectory coincide with the actual one obtained from the test result. The latter trajectory is conveniently superimposed upon the former by means of a transparent paper.

This is the case for zig-zag manoeuvre in general (in fact, not only zig-zag but any type of steering in principle). However, the procedure now in consideration becomes quite plain in the "limit-cycle" zig-zag manoeuvres, which means the zig-zag with a fixed period and amplitude. For this type of zig-zag tests, we need not input any rudder command signal. By adding an appropriate switching element, which is usually very simple, the analogue circuit sets in the limit cycle by itself, simulating the limit cycle zig-zag motion of a ship.

Fig. 1 shows a scheme of an analogue analyzer for yaw-rate zig-zag tests (a typical limit cycle zig-zag motion).



Switching Function : $\dot{\psi}$ reached r_s , δ_m^* switched to $-\delta_1$

$\dot{\psi}$ $-r_s$, δ_m^* δ_1

Fig. 1. Yaw-rate Zig-zag Analyzer - Schematic Diagram.

A limit cycle zig-zag test is particularly advantageous in the present type of analysis, because:

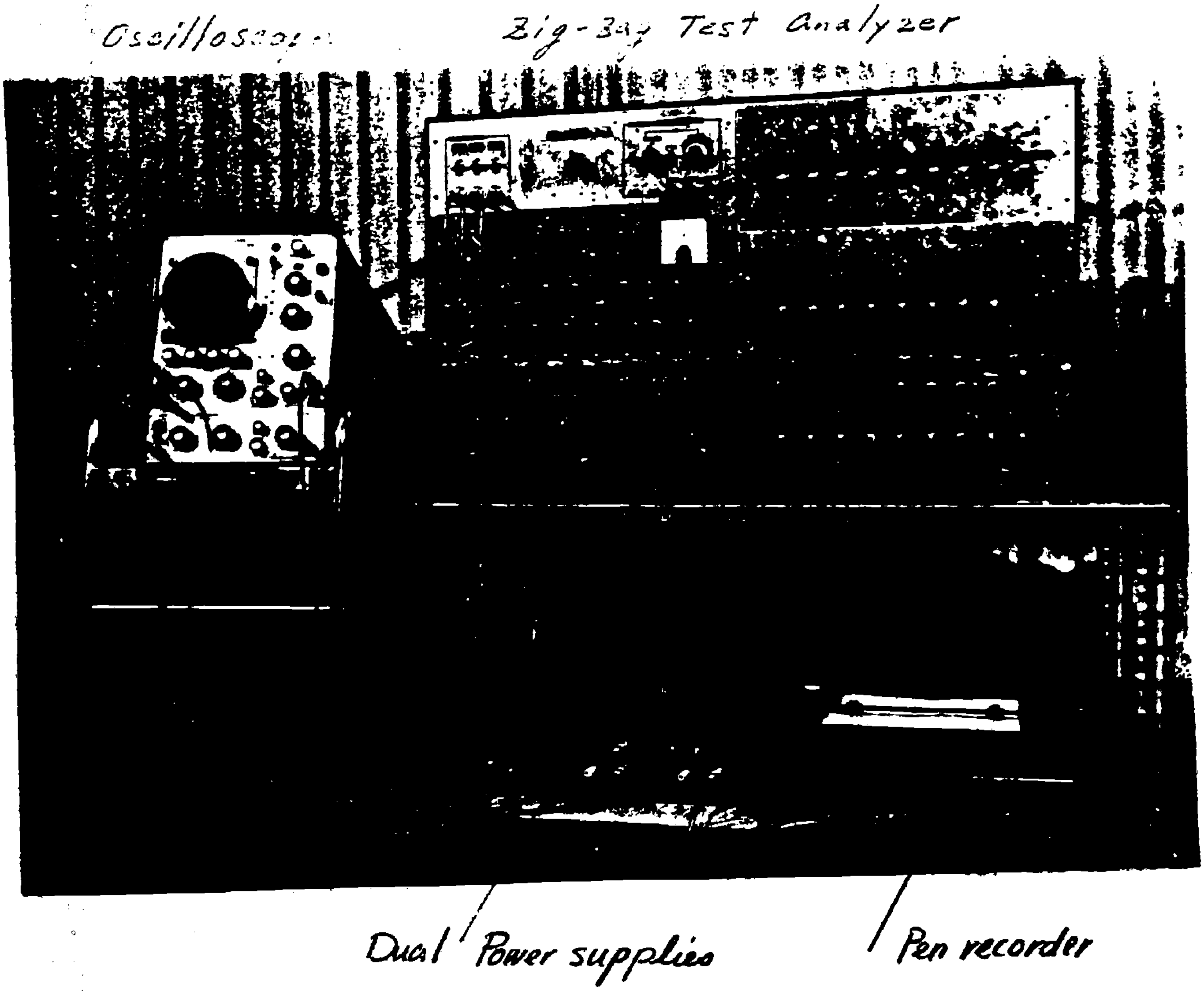
(1) the phase plane trajectory is a closed curve and thus visual iteration is simple and accurate;
(2) the ship's phase plane trajectory is accurate by averaging over periods. cf. another paper presented at the same meeting.

3. ACTUAL CIRCUIT AND PROCEDURE :

A picture of the set-up is shown on Fig. 2 and the block diagram of the circuit on Fig. 3. All the operational amplifiers and also the multipliers are of module type in the market.

Final reading of the potentiometer setting, which gives parameter figures, is done by means of a reference voltage and a digital-voltmeter, which is not shown in the figure.

Fig. 2. Zig-Zag Test Analyzer Set-up



Actual procedure of visual iteration is:

(1) to adjust K by the slope of the trajectory at the $\ddot{\varphi}$ axis (i.e., so as to fit the displayed slope to the one obtained from an actual test), T_1 by the width of the trajectory and δ_r by parallel shifting along the $\dot{\varphi}$ axis . along the φ axis -----Step 1, Fig.4.

(2) to adjust α by curve fitting at the 1st and 3rd quarters---- Step 2, and then make some correction to step 1 if needed;

(3) to adjust T_2 and T_3 by curve fitting at 2nd and 4th quarters and then make final touch-up -----Step 3.

4. SOME EXAMPLES:

(1) Mathematical Model: At first a mathematical model was employed to check the function of the device. The results are shown in Table 1.

Table 1

	math. model parameters	reproduced parameters with the analyzer 20°/0.5 °/s	15°/0.4 °/s	10°/0.3 °/s
K	-0.0432	-0.042	-0.042	-0.038
α	-7.32	-7.5	-7.5	-7.4
T_1	-208	-198	-198	-183
T_2	14.2	14	14	16
T_3	21.0	29	29	33

In this case the error comes only from visual iteration since the same type of mathematical model was used for giving the trajectory in place of actual one.

(2) Actual Ship Results: Two examples are shown in Table 2 and on Figs. 5 and 6. The car-ferry is a prototype of course-stable ships and the results shows that the linear model is also consistent in this case.

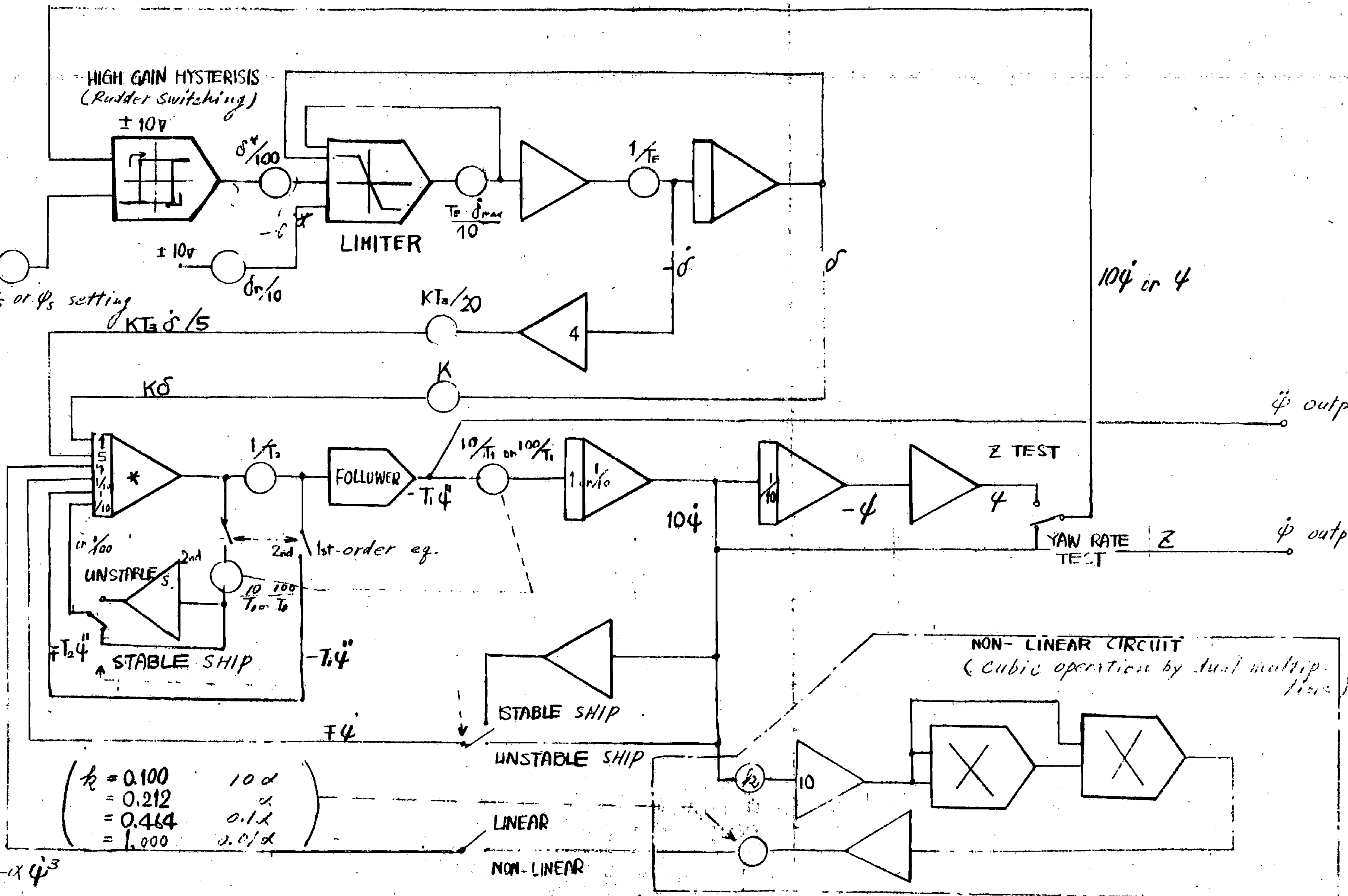
The other is a 200,000 DWT Class Tanker, representing unstable giant ships. The parameter figures obtained look reasonable and the observed motion of the ship in the form of phase plane portrait is nicely interpreted with these parameters and Eq. (1).

Table 2

	Car ferry 10°/0.25 °/s	same as left linear model	Tanker 10°/0.3 °/s
K	0.111	0.113	-0.0340
α	0.117	--	-18.2
T_1	21.8	21.6	-133
T_2	5.4	5.8	19.5
T_3	9.9	9.4	52.9

FIG. 3. ZIG ZAG ANALYZER – BLOCK DIAGRAM

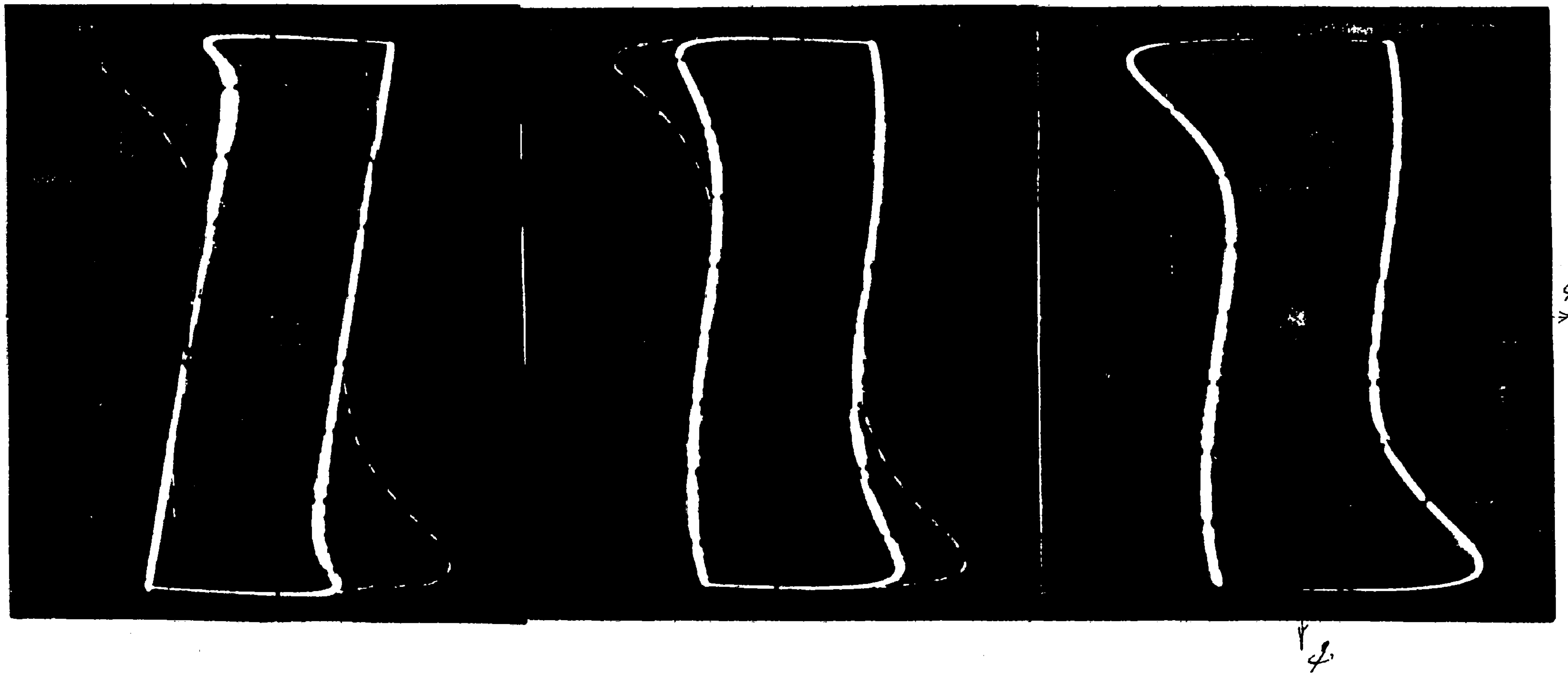
ψ, δ: $10^{\circ} \equiv 1v$, TIME SCALE $1 : 10^4$



$k = 0.100$	10α
$= 0.212$	α
$= 0.464$	0.1α
$= 1.000$	0.01α

* SUM. ADDER AT FIRST EQ. , 1/CR. OF INTEGRATORS IS 10^4 (AT HIGH SPEED OPERATION)
10 (AT LOW ")

ADJUST T_1, K_a, & δ_r ADJUST ~~#~~ α ADJUST T_2, T_3



STEP - 1 STEP - 2 STEP - 3

FIG. 4. VISUAL ITERATION.

--- observed trajectory
—— analyzer trajectory

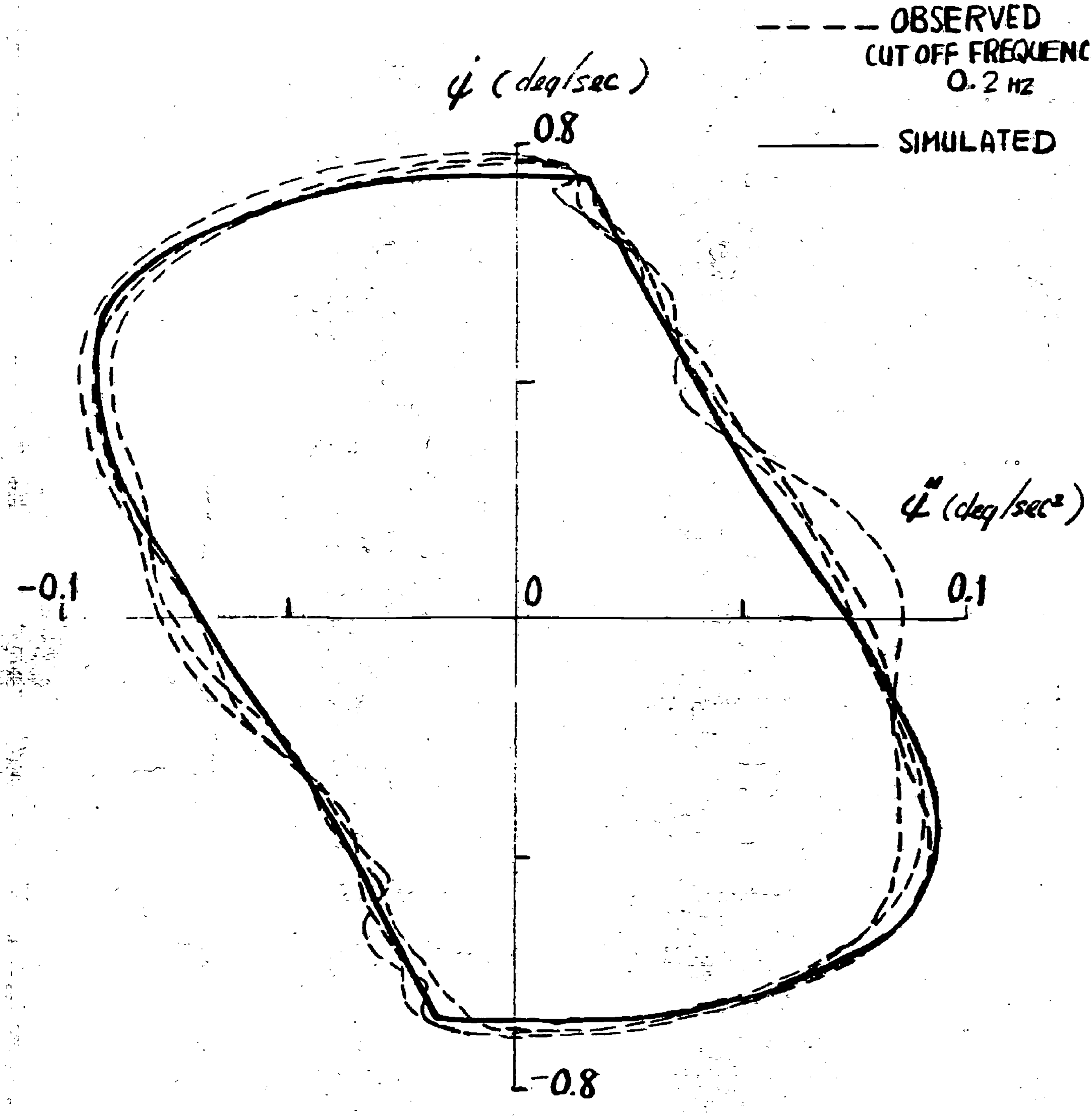


Fig 5 Car Ferry 10° - 0.75°/s YAW RATE Z

PHASE PLANE TRAJECTRY

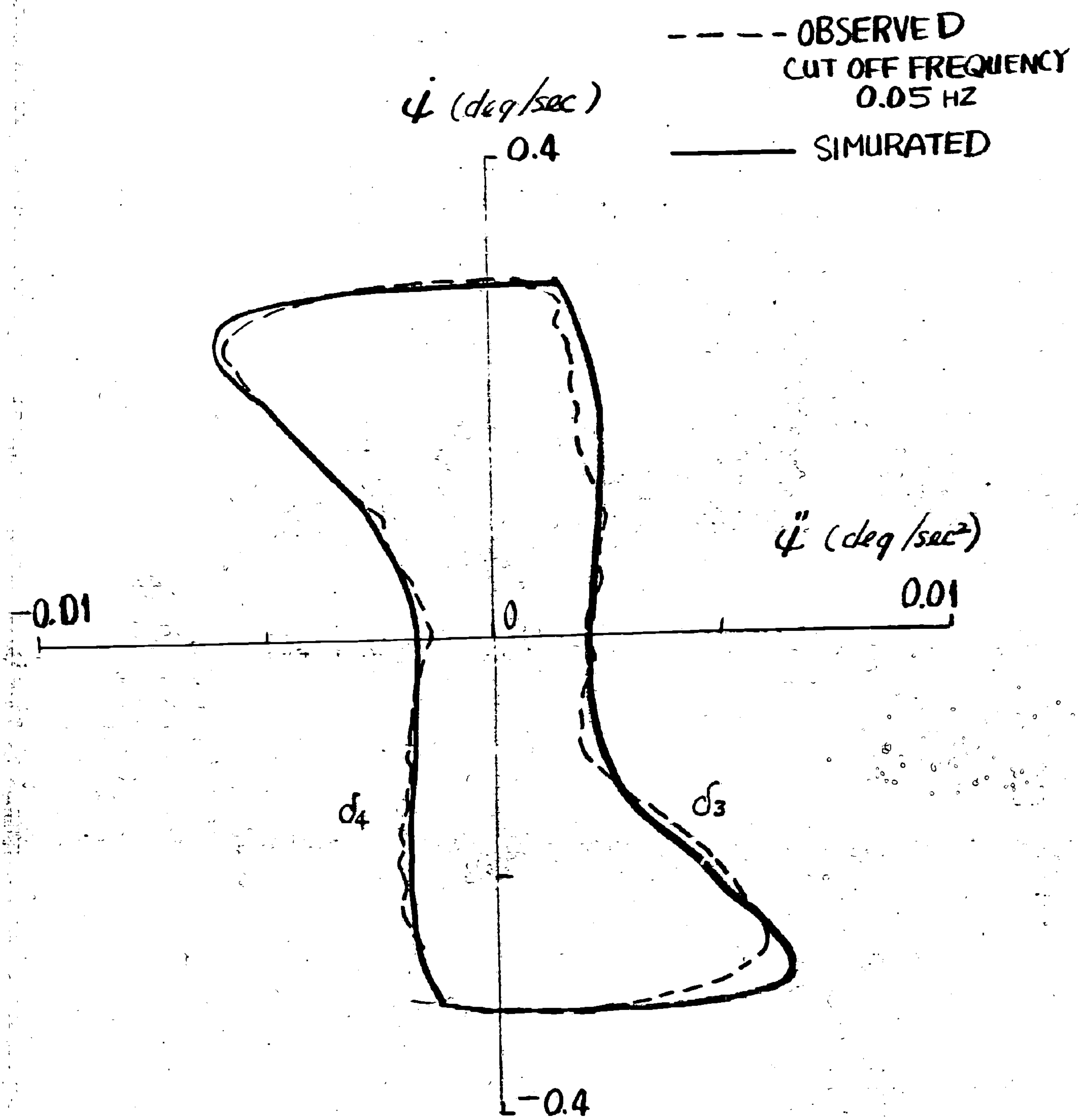


Fig. 6 TANKER 10° Z
PHASE PLANE TRAJECTORY