Optimization of direct injection Ricardo Hydra test engine on #2 diesel fuel / Optimisation du moteur d'essai à injection directe Ricardo hydra fonctionnant au carburant diesel n°2

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Optimization of Direct Injection Ricardo Hydra Test Engine on #2 Diesel Fuel

G.S. Messenger

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OPTIMIZATION OF DIRECT INJECTION RICARDO HYDRA

TEST ENGINE ON #2 DIESEL FUEL

OPTIMISATION DU MOTEUR D'ESSAI À INJECTION DIRECTE

RICARDO HYDRA FONCTIONNANT AU CARBURANT DIESEL N° 2

G.S. Messenger

This Memorandum is issued to furnish information in advance of a report. It is preliminary in character, has not received the careful editing of a report and is subject to review.

Le présent mémoire est à caractère préliminaire. Il est mis en circulation afin de fournir des renseignements et il sera sujet à révisions.

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ABSTRACT

This report describes the injection timing optimization of the direct injection Ricardo Hydra single cylinder research engine on #2 diesel fuel at the NRC Engine Laboratory. The engine installation was designed for performance testing of diesel fuels in the direct and indirect injection configurations.

RÉSUMÉ

Le présent rapport décrit l'optimisation de l'avance à l'injection du moteur d'essai monocylindrique à injection directe Ricardo Hydra fonctionnant au carburant diesel n° 2 effectuée au Laboratoire des moteurs. L'installation du moteur a été conçue dans le but d'effectuer des essais de rendement des carburants diesel dans des conditions d'injection directe et indirecte.

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LIST OF SYMBOLS

Symbol		Units
ABDC	After Bottom Dead Centre	-
ATDC	After Top Dead Centre	-
API	American Petroleum Institute	-
ASTM	American Society for Testing Materials	-
AVL	AVL LIST Ges.m.b.H., Graz, Austria	-
BBDC	Before Bottom Dead Centre	-
BTDC	Before Top Dead Centre	-
BMEP	Brake Mean Effective Pressure	kPa
BSFC	Brake Specific Fuel Consumption	g/kWh
CGSB	Canadian General Standards Board	-
cSt	Centistokes	-
CR	Crankshaft	-
DEG	Degree, angular	-
°C	Degree Celsius	-
DI	Direct Injection	-
g	Gram	-
g/kWh	Grams per kilowatt hour	-
h	Hour	-
kPa	Kilopascals	-
kW	Kilowatt	-

CONTENTS (Cont'd)

LIST OF SYMBOLS (Cont'd)

Symbol		**Units**
1	Litre	-
1/h	Litres per hour	-
MJ/kg	Megajoule per kilogram	-
MPa	Megapascals	-
mm	Millimetre	-
NRC	National Research Council	-
N.m	Newton metre	-
REC	Nicolet oscilloscope record number	-
rev/s	Revolutions per second	-
T/D	Time per division	s
TL	Time reference at Left edge	s
TDC	Top Dead Centre	-
SAE	Society of Automotive Engineers	-
SN	(Bosch) Smoke Number	-
V	Volt	-
V/D	Volts per Division	V
v_y	Y axis' reference voltage	V

OPTIMIZATION OF DIRECT INJECTION RICARDO HYDRA TEST ENGINE ON #2 DIESEL FUEL

1.0 INTRODUCTION

The test engine installation was designed to test performance of low Cetane Number, tar sands derived diesel fuels compared with standard commercially available #2 diesel fuel.

Before beginning performance tests it was necessary to optimize the injection timings on #2 diesel fuel, since other fuels would be run in comparison with the same timings.

This was part of a series of tests being conducted on various automotive and medium speed diesels by the NRC and the Department of National Defence.

2.0 OBJECTIVES

The objective of this task was to find the optimum injection timings for the direct injection Ricardo Hydra test engine while running on commercially available #2 diesel fuel. Timings are required for full load at Bosch Smoke Number 4 and at light and medium load conditions.

3.0 TEST ENGINE

The Ricardo Hydra single cylinder test engine (Messenger, 1991; French, 1983) is installed in the Engine Laboratory at NRC, Ottawa, Canada. Engine specifications are listed in Table 1. It can be configured as a gasoline or diesel engine by changing the piston, cylinder, cylinder head and fuel system components. The crankcase and crankshaft are common for all configurations. Compression ratios can only be changed by changes to piston crowns and combustion chambers. All configurations use a toothed belt drive to an overhead camshaft which operates both (inlet and exhaust) valves through bucket type tappets. Valve clearance is set by shims between the valve stem and the bucket tappet. Camshaft timing can be adjusted by means of its drive pulley which has a moveable, lockable centre section. Drive to the diesel injection pump is also by a toothed belt to a similar pulley. Initial static injection pump timing (spill timing) is adjusted by this pulley. The flywheel is on the dynamometer side of the engine and has multiple tracks of degree notches machined into its periphery for various timing pickups. The opposite end of the crankshaft has a fitting for hand barring of the engine. The pistons of all configurations have two compression rings, one oil control ring and solid skirts.

Figure 1 shows the cross section through the DI combustion chamber. Figure 2 is a photograph of the installed engine. Figure 3 is a photograph of the control panel.

The dynamometer is used as a direct current motor to start the engine in all configurations. Output power from the dynamometer is converted by silicon rectifiers from direct current into alternating current and added into the laboratory's power system. The dynamometer has its own cooling blower.

Engine coolant and crankcase oil are cooled by a two-section tube heat exchanger which uses city water as coolant. Warm water from the heat exchanger is not recycled.

Both coolant and oil are circulated by separately driven electric pumps rather than by the engine. Maximum coolant flow is 1900 1/h while maximum oil flow is 545 1/h at 400 kPa.

Heaters are built into the inlet air manifold, the coolant system and the crankcase. The air heater is 1 kW and permits operation at a constant inlet temperature. The coolant heater is .5 kW and the oil heaters in the crankcase total 2 kW.

4.0 INSTRUMENTATION

The Ricardo Hydra test engine's installation, instrumentation,and modifications have been described previously (Messenger, 1991).

Instrumentation installed permitted direct measurement of the following:

- speed
- torque
- Bosch Smoke Number
- airflow
- fuel mass flow
- crankshaft degrees
- injector needle lift
- cylinder pressure
- fuel pressure at injector
- blowby volume flowrate
- crankcase pressure
- oil pressure
- fuel pressure at injection pump
- exhaust pressure
- exhaust temperature
- inlet air temperature
- fuel temperature at inlet to injection pump
- coolant temperature
- oil temperature
- wet bulb temperature
- dry bulb temperature
- barometric pressure

5.0 TEST PROCEDURE

5.1 General

All testing was done on the same batch of commercially available #2 diesel fuel. Its characteristics were measured by the NRC Combustion and Fluids Engineering Program and are listed in Table 2. A fuel consumption mass of 30 g was used for all tests and gave minimum consumption times of approximately 40 seconds at high speed and full load.

All speed changes required the injection timing to be changed as the speed increased or decreased.

To enable comparisons to be made from run-to-run the SAE Power Test Code (SAE J1349 JUN85) was used to set initial test condition variables and to correct performance values.

For these tests inlet air and fuel were heated to 40°C while coolant and engine oil were maintained at 80°C. At low speeds both oil and coolant heaters had to be manually controlled to maintain temperature. Inlet air and fuel systems have closed loop heater controls for maintaining temperatures. The coolant used was a 50/50 mixture of glycol and water. Engine oil used for all tests was Esso XD3 15W40.

After the daily checks of fluid levels, potential leaks and safety devices, calibrations were done on the Bosch Smoke Meter and the dynamometer load cell. Readings were taken of wet and dry bulb temperatures and barometric pressure. The warmup at the beginning of a test consisted of moderate load at 25 rev/s until the coolant and oil temperatures reached 60°C. When higher speed set-points were desired, the injection timing was changed to correspond to 40 rev/s as an intermediate set-point; the fuel quantity was increased until Bosch Smoke Number 4 was reached and the coolant and oil reached 80°C. Usually the 80°C oil temperature set-point was reached before the coolant even though both systems made use of electric heaters. Typical warmup times would range from 30 to 45 minutes.

Data were recorded manually at each set-point. The digital oscilloscope was used to make recordings of cylinder pressure, crankshaft degrees, needle lift and high pressure fuel. A series of consecutive pressure traces was photographed on the analog oscilloscope during some runs.

At the end of each constant speed test sequence, the fuel was shut off (rack returned to zero) and the engine was motored at the same speed.

5.2 Full load Tests

For full load smoke-limited tests, once the desired speed and injection timing were set, only the rack setting had to be adjusted until Bosch Smoke Number 4 was reached. Once steady state conditions at Bosch Smoke Number 4 were reached, the throttle control (rack) was locked and data were taken.

While at the specified constant speed setting and with locked rack, the injection timing was retarded, in one step, to a predetermined timing point closest to TDC. From this point injection timing was advanced in two degree steps to find the most retarded (closest to TDC) injection timing where the BMEP (or torque) began to fall. A repeat of the initial set-point reading was done at the end of the run. A complete set of readings was taken manually once the engine had stabilized at each injection timing. Ricardo injection timings listed in Table 3 were used as the initial start point for each speed.

Initial tests were done using the Ricardo mechanism for rotating the high pressure injection pump to change the timing. These tests were repeated with the AVL variable phase angle gear box.

Speeds tested were 30, 40, 50, 60, 65, 70, and 75 rev/s.

5.3 Part Load Tests

Besides having an initial injection timing and a given speed, a constant torque set-point was required which corresponded to a specified part load. Each set-point required manual entry of observed data into the Digital 11/34 computer to give the corrected torque (to the SAE test code J1349) for the current atmospheric conditions. Adjustment of the rack was usually necessary to achieve the desired torque set-point. Ricardo injection timings listed in Table 3 were again used for the initial start point for each speed. When the corrected start set-point was repeatable, the rack was locked at this position and the injection timing was then retarded in one step to a predetermined retarded timing, closest to TDC. The injection timing was then advanced in steps of two degrees, with the rack still locked, to locate a minimum BSFC. A final set-point in each run was a return to the first injection timing used.

Speeds tested were peak torque at 40 rev/s, maximum power at 65 rev/s and maximum rated speed at 75 rev/s.

6.0 RESULTS

Table 4 summarizes the optimized static injection timings for Bosch Smoke Number 4. The timing entered for 25 rev/s was not optimized during tests with the AVL variable phase angle gear box but was derived from earlier tests with the original Ricardo mechanism and is included for engine starting reference.

Table 5 summarizes the optimized static injection timings for part load conditions at 40, 60, and 75 rev/s.

The plotted test data for Figures 4 to 27 are from the most retarded to the most advanced injection timing in two degree steps. The first and last set-points which were at the Ricardo timing are not plotted but the Ricardo set-point is repeated within each plot.

Figures 4 to 17 are typical smoke limited plots of torque, BSFC, power and Bosch Smoke Number plotted against static injection timing in degrees BTDC for the smoke limited tests at 30, 40, 50, 60, 65, 70, and 75 rev/s.

Figures 18 to 27 are typical plots of torque, BSFC, power and Bosch Smoke Number plotted against static injection timing in degrees BTDC for the part load tests at 40, 65, and 75 rev/s.

Cylinder traces of typical complete runs including initial set-point and final set-point check are shown in Figures 32 to 38, 41 to 47 and 53 to 59. These runs correspond to the static injection timing plots of Figures 10, 11, 16, 17, 26 and 27. The remaining cylinder traces are either a) the trace at the optimum timing or b) the trace one degree either side of the optimum timing. A line has been added at the TDC mark on all cylinder trace figures to aid in making comparisons.

The legend on Figures 28 to 59 is interpreted as follows: V/D is voltage per division in the Y direction; Vy is the voltage at "Vy" designated on the Y axis; T/D is the time per division on the X axis and TL is the time reference at the origin on the X axis. The four curves from top to bottom in Figures 28 to 59 are: degrees crank angle, cylinder pressure, injector needle lift and fuel pressure at the injector.

Figures 28 to 48 are typical cylinder trace averages of 10 cycles for the smoke limited tests at 30, 40, 50, 60, 65, 70, and 75 rev/s. Of these Figures 32 to 38 are of run #1 April 3, 1986, at 60 rev/s. Figures 32, 35 and 38 are the original set-point timing with Figure 33 the most retarded and Figure 37 the most advanced. Figures 41 to 47 are run #2 April 3, 1986, at 75 rev/s. Figures 41, 44 and 47 are the original set-point timing. Figure 42 is the most retarded while Figure 46 is the most advanced.

Figures 49 to 59 are cylinder trace averages of 10 cycles for the part load tests. Figures 53 to 59 are of run #3 April 18, 1986, part load at 75 rev/s and 7.2 N.m torque (200 kPa BMEP). The original set-point timing is shown in Figures 53, 56 and 59 while Figure 54 is the most retarded and Figure 58 is the most advanced.

7.0 DISCUSSION OF RESULTS

In the determination of optimum injection timing in the smoke limited tests, it was found that the fall-off in torque (BMEP) did not always coincide with the minimum BSFC at each speed. The cylinder trace was also studied for each timing and it was noted that the TDC location in the cylinder pressure rise was at or near the minimum BSFC when TDC occurred midway on the pressure rise after fuel injection.

Determination of optimum injection timing in the part load tests was based on the minimum BSFC and the location of TDC in relation to the cylinder pressure rise. Also it was found that when the TDC location occurred midway on the cylinder pressure rise, the BSFC was at or close to a minimum.

A comparison of the new timings with Ricardo's showed that increases of up to 4 degrees were required at the lower speeds; they were identical at 60 and 70 rev/s and at 75 rev/s a decrease of one degree was needed. The same low and high speed timing trends were previously observed when the Ricardo timing mechanism was used. This indicated the shift was caused by operating on North American #2 diesel fuel rather than the change to a shorter, larger inside diameter and larger outside diameter high pressure injection line listed in Table 1 and discussed by Messenger (1991).

8.0 CONCLUSIONS

Injection timings for #2 diesel fuel have been determined for the smoke limited case over the speed range of 30 to 75 rev/s. Part load injection timings have been determined at 40, 65 and 75 rev/s.

Comparison tests with other fuels may now be done in this engine.

9.0 RECOMMENDATIONS

Complete the computer data acquisition system hookup to measure slowly changing variables and provide an on-line update of corrected output.

Redesign the engine-to-dynamometer shaft to allow operation at typical automotive idle speeds.

10.0 ACKNOWLEDGEMENTS

Thanks to Joe Murphy, Reg Smith and Russ Thibedeau for their skilful assistance, recommendations and persistence.

Thanks to Boris Glavincevski and Roy Sabourin of the Combustion and Fluids Engineering Program for fuel analysis.

11.0 REFERENCES

French, C.C.J. 1983. *A Universal Test Engine For Combustion Research*. SAE paper 830453.

Messenger, G.S. 1991. *Installation and Instrumentation of Ricardo Hydra Test Engine*. NRC report IME-MET-LM-001.

Society of Automotive Engineers. 1986. *Power Test Code J1349 JUN85*. 1986 SAE Handbook, Volume 3: 24.08-24.10.

Table 1. DI Hydra Engine Specifications.

Ricardo serial number	27
combustion system	DI, naturally aspirated, 4 stroke, bowl in piston
bore/stroke	80.6/88 mm
displacement	0.45 1
compression ratio	18.2:1
output	smoke limited to 8 kW
maximum/minimum speed	75/20 rev/s
valves	1 inlet, 1 exhaust, overhead cam
inlet valve opens	10° BTDC
inlet valve closes	42° ABDC
exhaust valve opens	58° BBDC
exhaust valve closes	10° ATDC
injection pump	Mico Bosch A type EO 4000 6900 9 mm plunger diameter 55 mm^3 delivery valve unloading volume
injector nozzle	type DLLA155PV 3172325 4 holes 0.21 mm diameter at 155° 25 MPa opening pressure
injector body	Bosch KBEL 88PV1187
injector fuel line	6.45 mm outside diameter 1.57 mm inside diameter 280 mm long

Table 2. #2 Diesel Fuel Characteristics

Distillation (ASTM D86)	
Initial Boiling point	175°C
10% recovered	200°C
50% recovered	247°C
90% recovered	308°C
Final Boiling Point	342°C
Recovered % volume	98.5
Residual % volume	1.1
Loss % volume	0.4
API Gravity (ASTM D1298)	36.9
Relative Density @ 15.56°C	0.8403
Heat of Combustion net MJ/kg, (CGSB 3-GP-0-23.4M)	45.71
Kinematic Viscosity cSt @40 °C	2.08
Cloud Point (ASTM D2500)	-21°C
Pour Point (ASTM D97)	-36 °C
Elemental Analysis - mass %	
Sulphur (ASTM D4294)	0.24
Carbon	na
Hydrogen (ASTM D3701)	13.1

Table 2. #2 Diesel Fuel Characteristics (cont'd)

Fluorescent Indicator Analysis FIA (ASTM D1319) volume %	
Saturates	70.4
Olefins	0.6
Aromatics	29.0
Low Resolution Mass Spectrometry	
n-alkanes	na
Iso-alkanes	na
Cyclo-alkanes	35.2
Total Paraffins	71.0
Total aromatics	29.0
Polars and unidentified	na
Proton Nuclear Magnetic Resonance 'H NMR mass %	
Paraffins	64.9
Aromatics	35.1
Cetane Number (ASTM D613)	45.9

Table 3. Static Injection Timings for Bosch Smoke Number 4
DI Ricardo Hydra Test Engine

Engine Speed rev/s	Static Injection degrees BTDC
20	8
30	12
40	15
50	19
60	22
70	26
75	28

Table 4. Optimized Static Injection Timings for Bosch Smoke Number 4
DI Ricardo Hydra Test Engine

Engine Speed rev/s	Static Injection degrees BTDC
25	12*
30	16
40	18
50	20
60	22
65	23
70	26
75	27

* not optimized, included for starting setting

Table 5. Optimized Static Injection Timings For Part Load Conditions, Ricardo DI Hydra Test Engine

Engine Speed rev/s	BMEP kPa	Torque N.m	Static Injection degrees BTDC
40	200	7.16	21
40	400	14.32	19
65	200	7.16	28
75	200	7.16	31

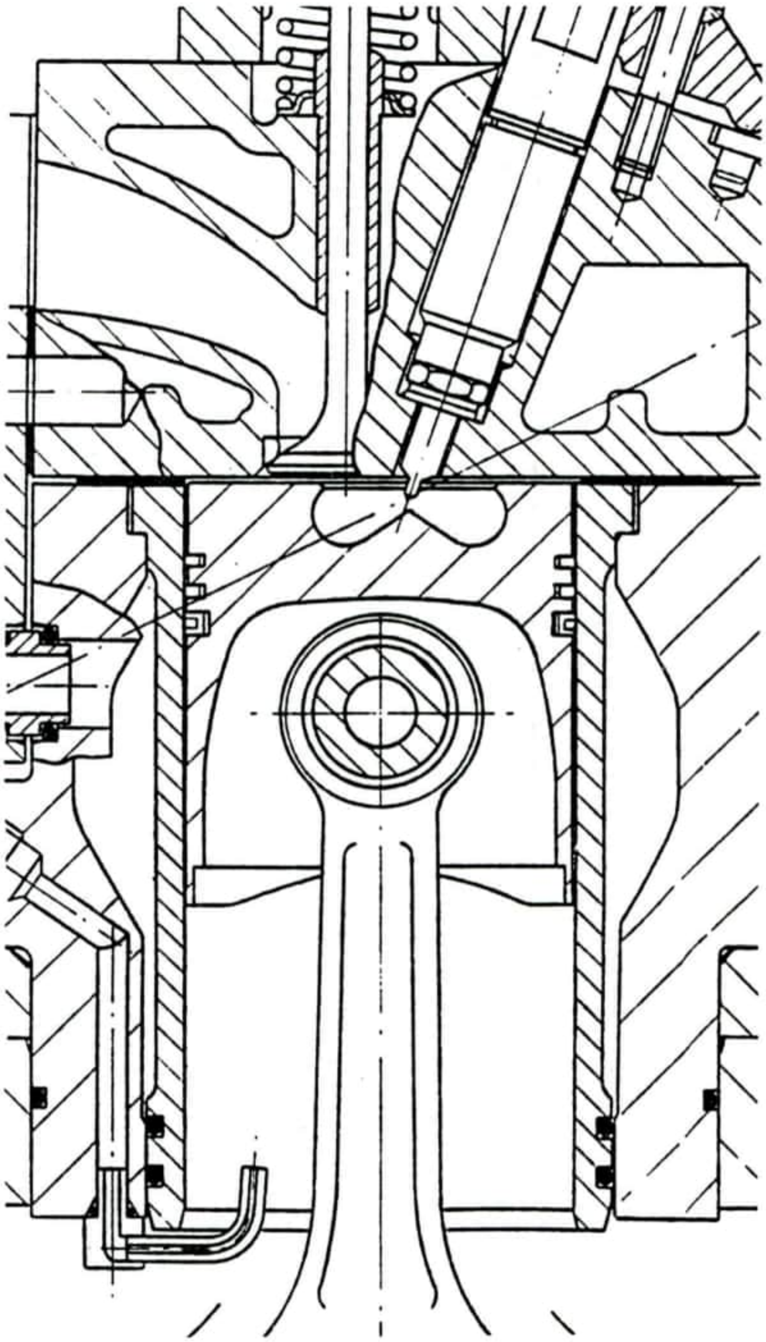

Figure 1. Cross section through DI combustion chamber.

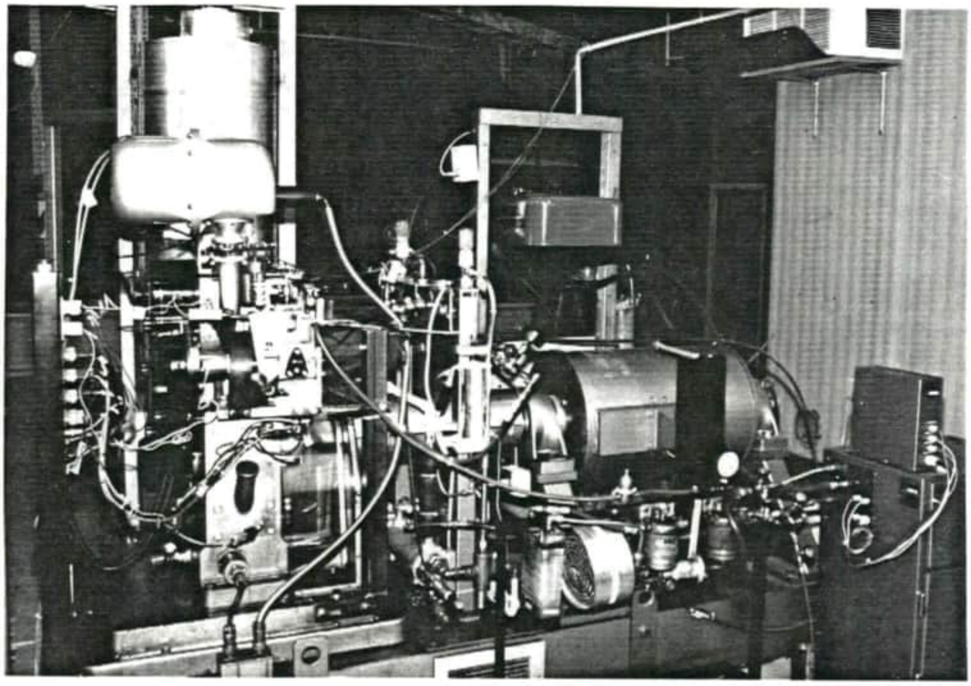

Figure 2. Ricardo Hydra test engine.

Figure 3. Control Panel.

Fig. 4 BRAKE TORQUE & BSFC vs STATIC INJECTION TIMING 30 REV/S

RUN 1, MARCH 26, 1986, SET POINT -12 degrees crank @ SN = 4

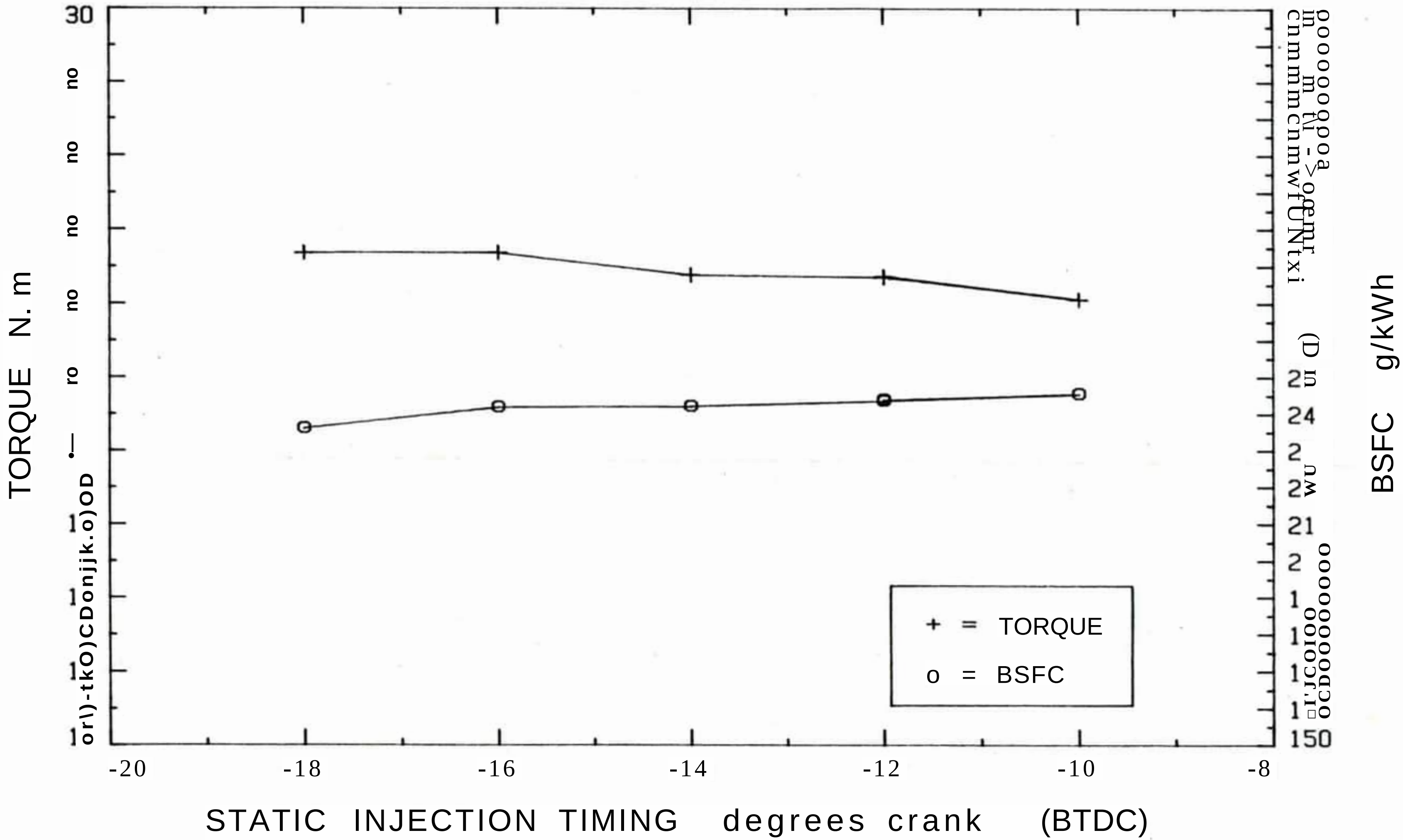

Fig. 5 BRAKE POWER & BOSCH SN vs STATIC INJECTION TIMING 30 REV/S

RUN 1, MARCH 26, 1986, SET POINT -12 degrees crank @ SN = 4

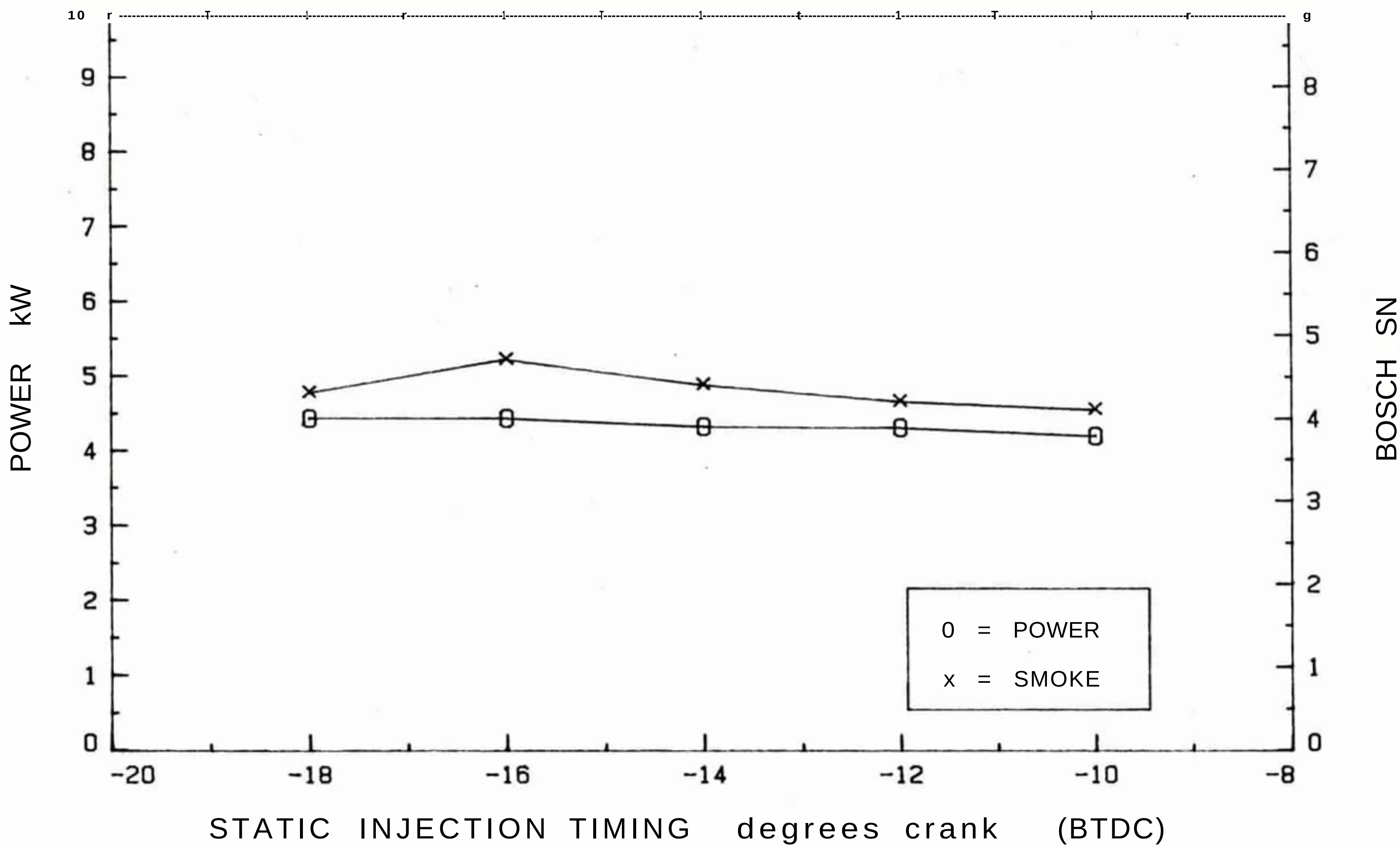

Fig. 6 BRAKE TORQUE 8. BSFC vs STATIC INJECTION TIMING 40 REV/S

RUN 1, APRIL 14, 1986, SET POINT -15 degrees crank @ SN = 4

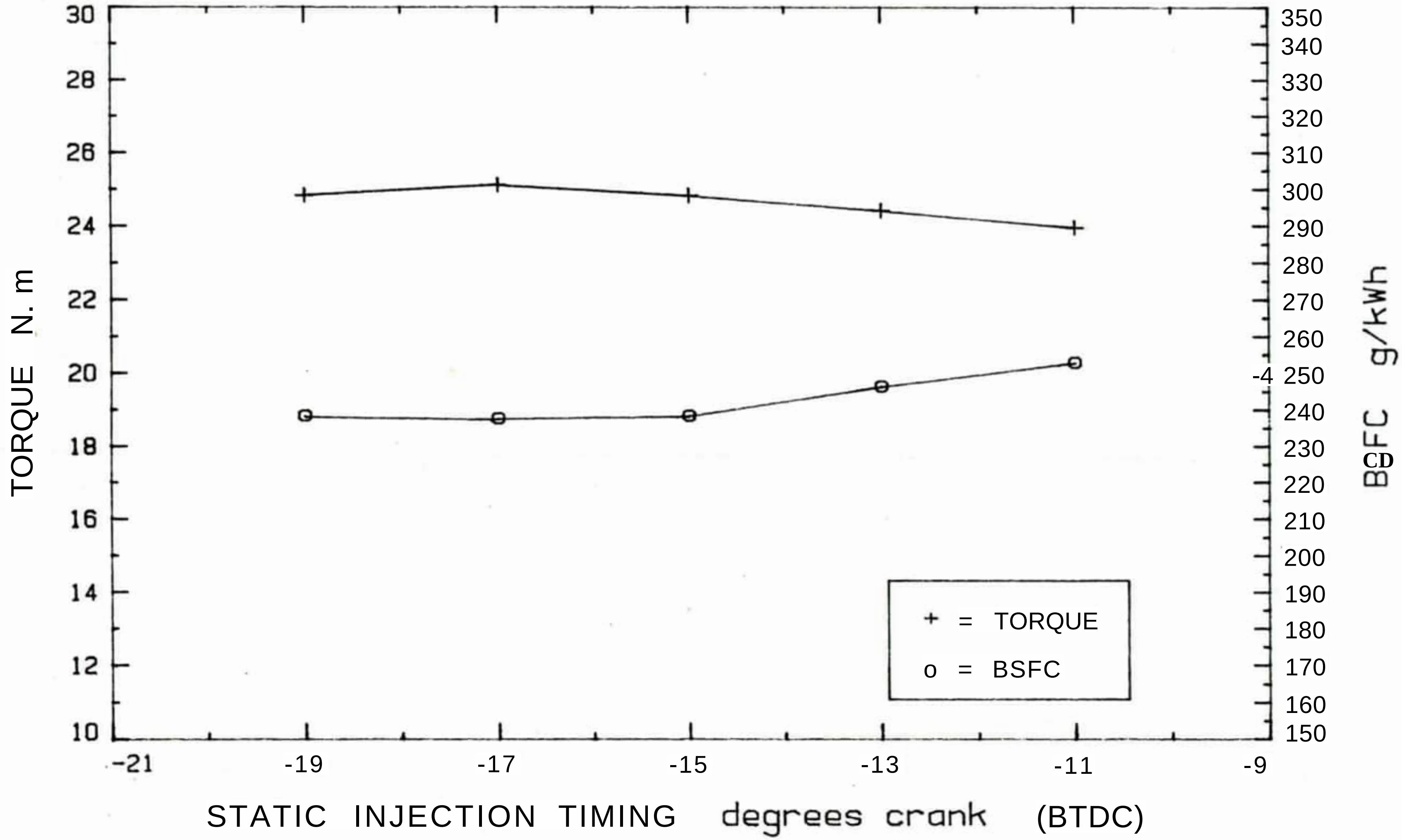

Fig. 7 BRAKE POWER & BOSCH SN vs STATIC INJECTION TIMING 40 REV/S

RUN 1, APRIL 14, 1986, SET POINT -15 degrees crank @ SN = 4

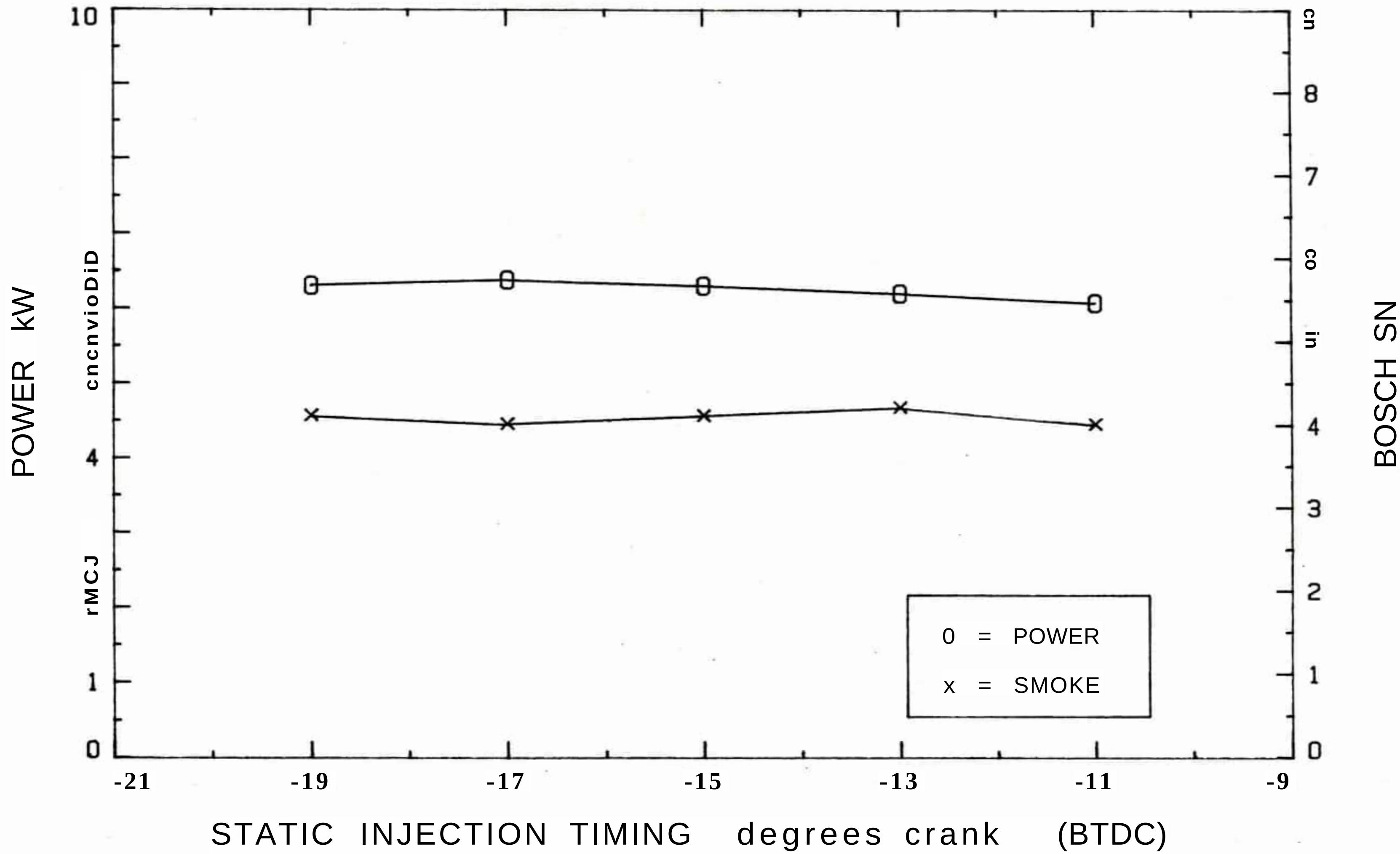

Fig. 8 BRAKE TORQUE & BSFC vs STATIC INJECTION TIMING 50 REV/S

RUN 3. MARCH 26, 1986, SET POINT -19 degrees crank @ SN = 4

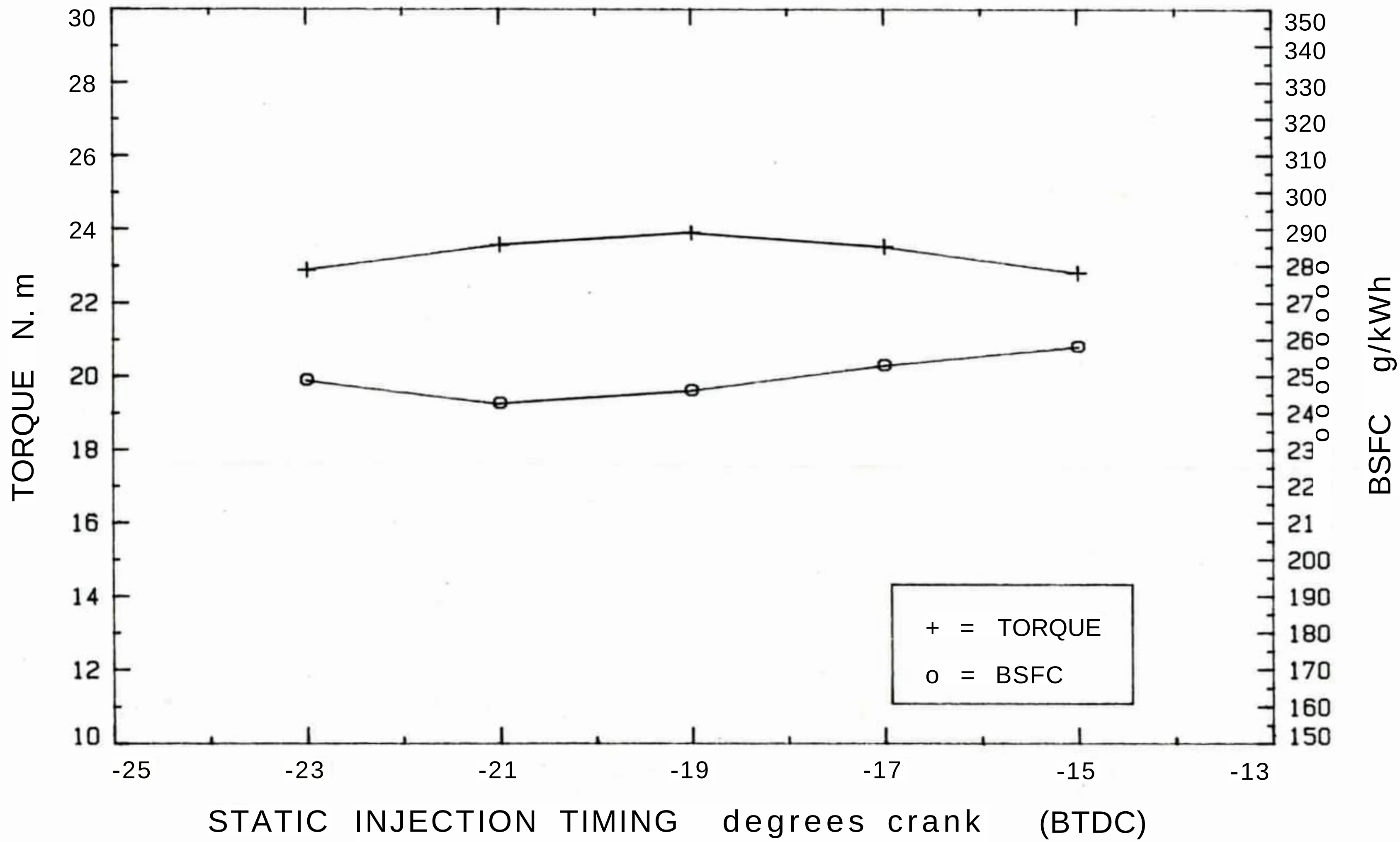

Fig. 9 BRAKE POWER & BOSCH SN vs STATIC INJECTION TIMING 50 REV/S

RUN 3, MARCH 26, 1986, SET POINT -19 degrees crank Is! SN = 4

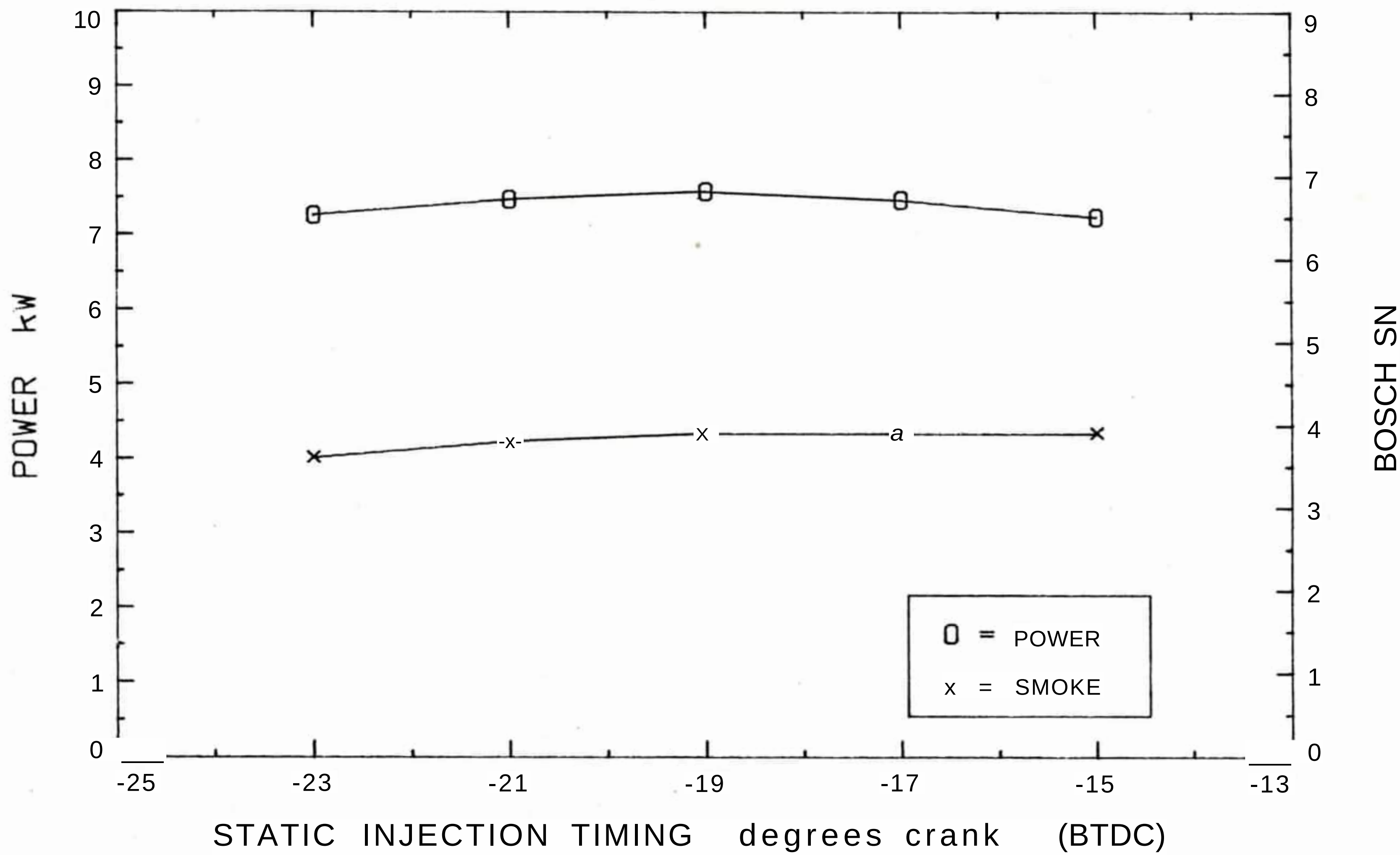

Fig. 10 BRAKE TORQUE & BSFC vs STATIC INJECTION TIMING 60 REV/S

RUN 1, APRIL 3, 1986, SET POINT -22 degrees crank @ SN = 4

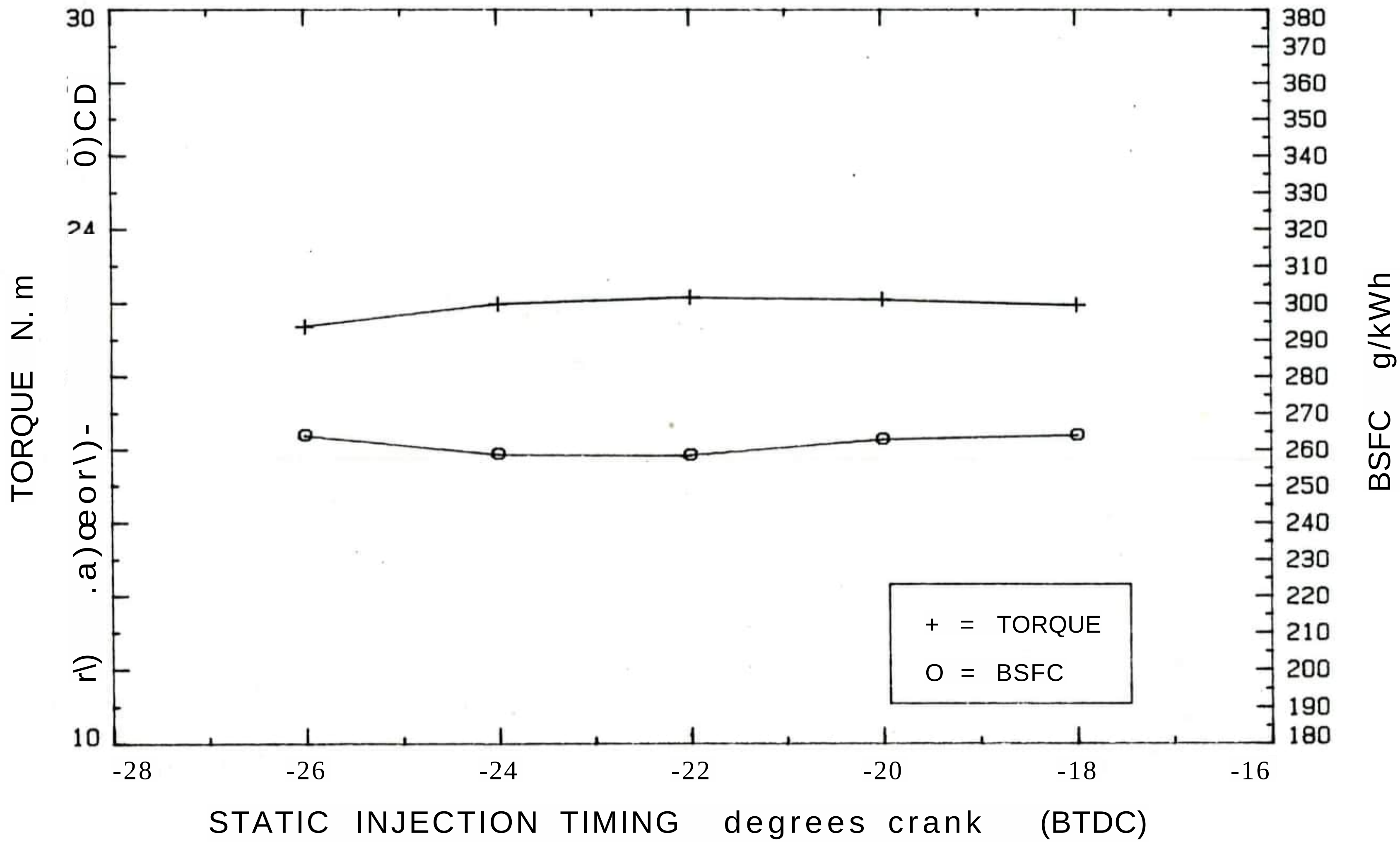

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Fig. 11 BRAKE POWER & BOSCH SN vs STATIC INJECTION TIMING 60 REV/S

RUN 1, APRIL 3, 1986, SET POINT −22 degrees crank @ SN = 4

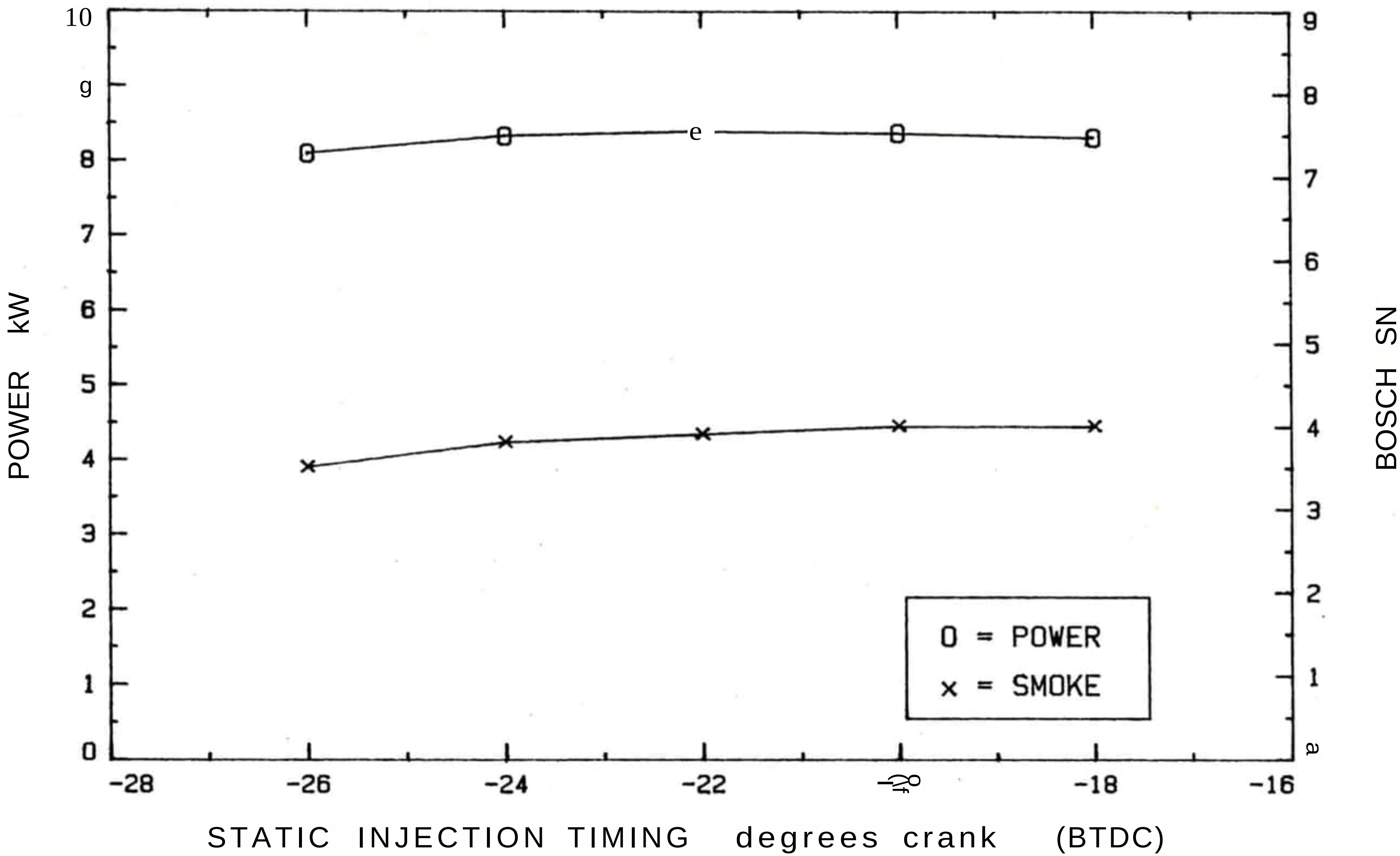

Fig. 12 BRAKE TORQUE & BSFC vs STATIC INJECTION TIMING 65 REV/S

RUN 3, APRIL 17, 1986, SET POINT -24 degrees crank © SN = 4

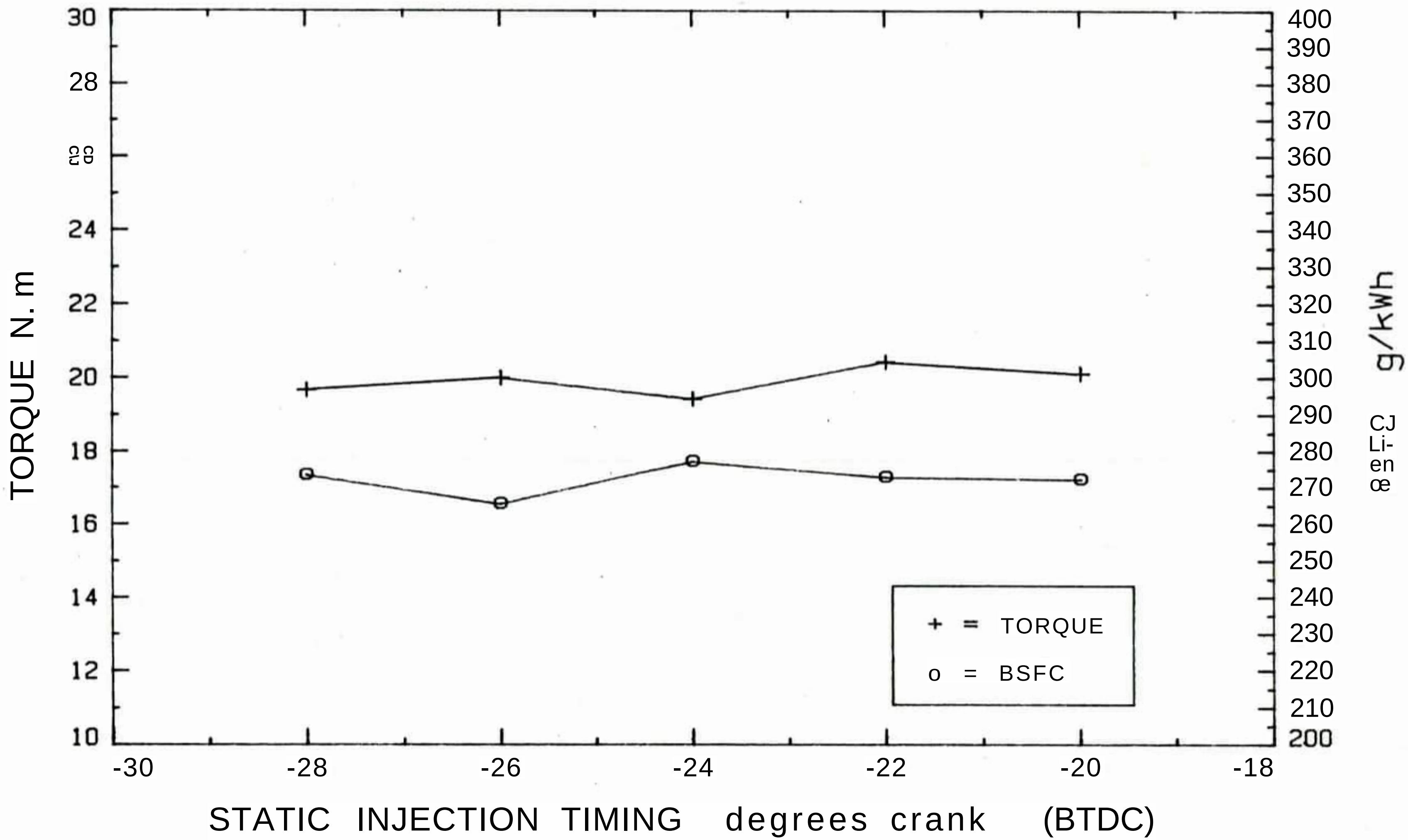

Fig. 13 BRAKE POWER & BOSCH SN vs STATIC INJECTION TIMING 65 REV/S

RUN 3, APRIL 17, 1986, SET POINT -24 degrees crank @ SN = 4

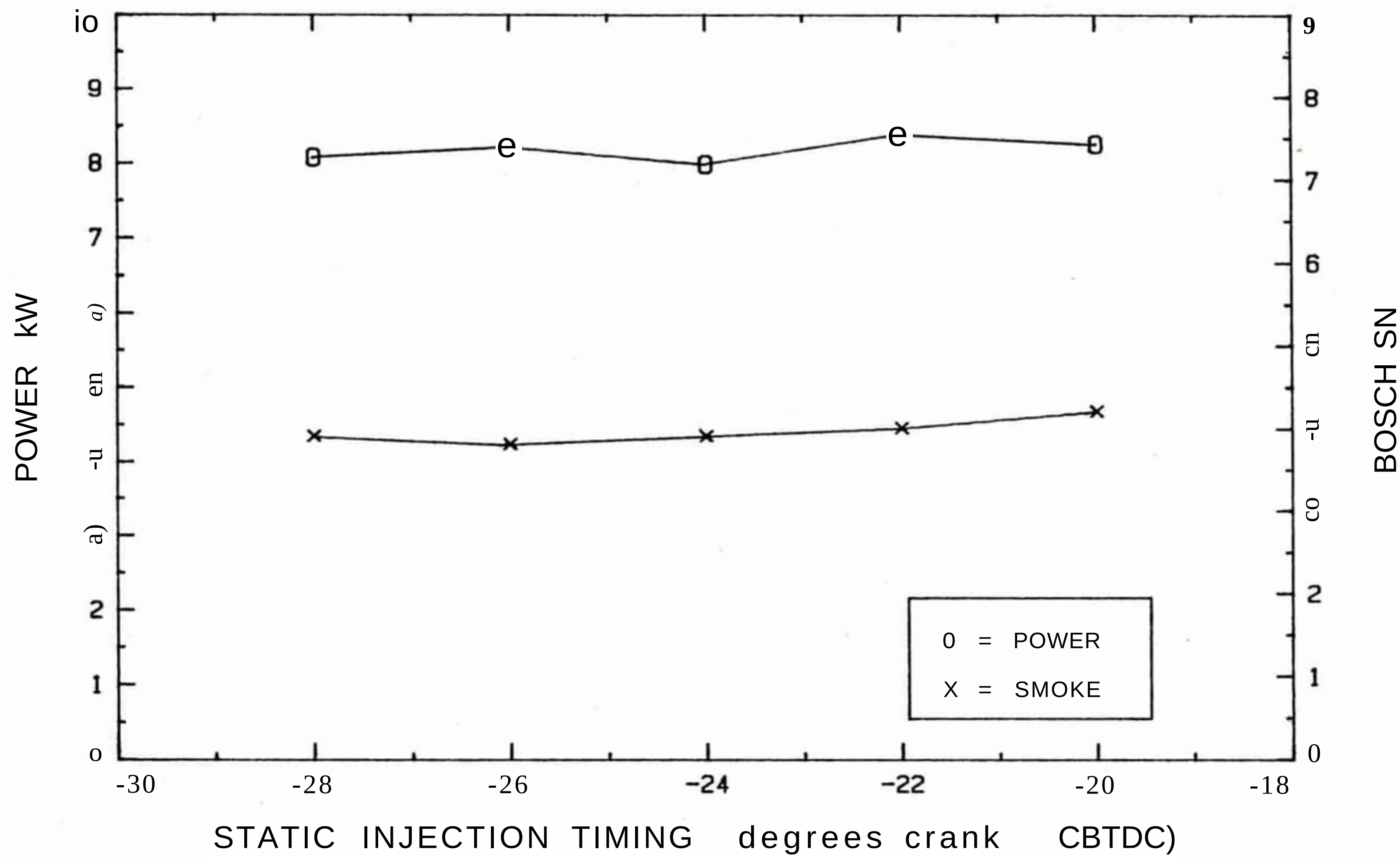

Fig. 14 BRAKE TORQUE & BSFC vs STATIC INJECTION TIMING 70 REV/S

RUN 2, APRIL 2, 1986, SET POINT -26 degrees crank @ SN = 4

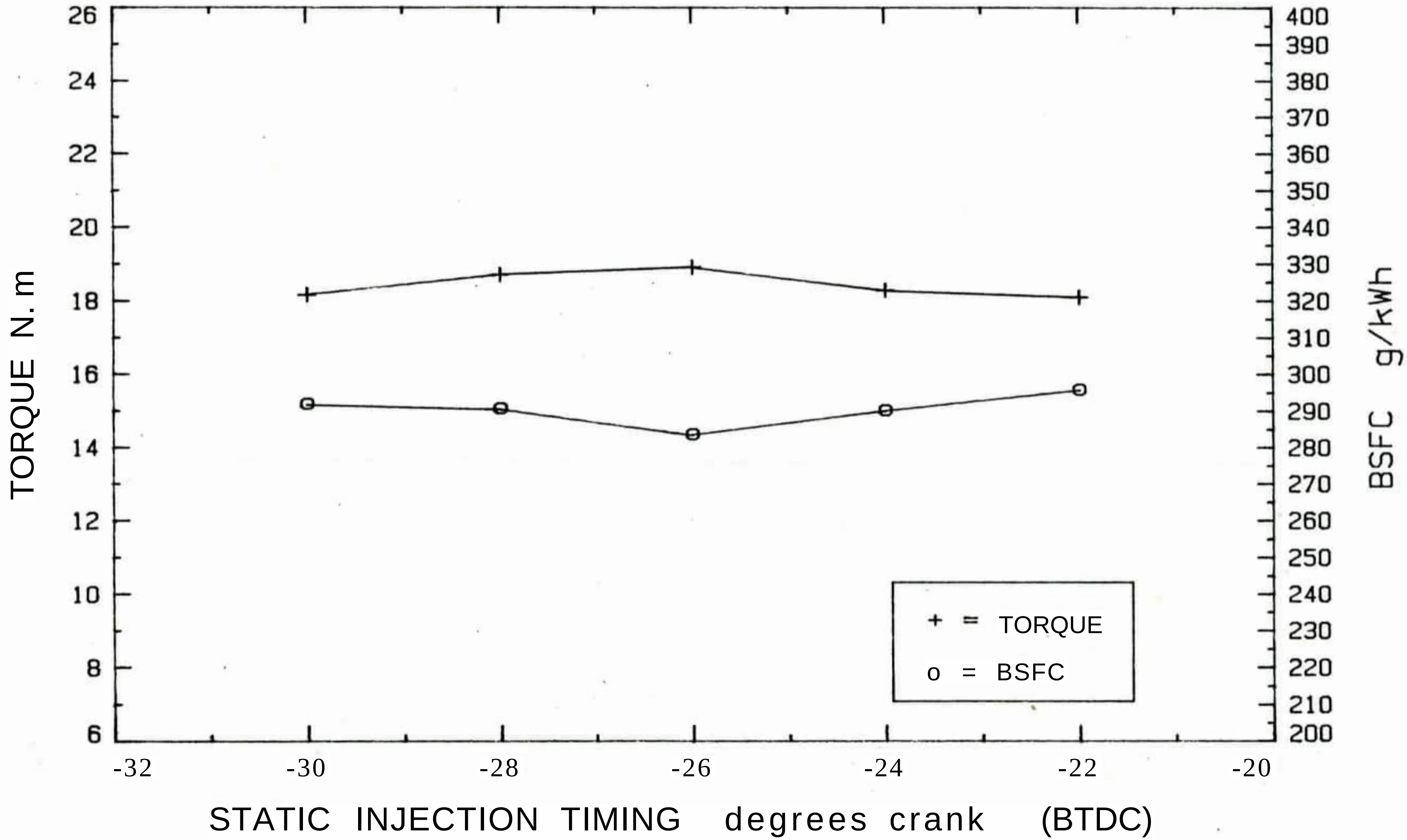

Fig. 15 BRAKE POWER & BOSCH SN vs STATIC INJECTION TIMING 70 REV/S

RUN 2, APRIL 2, 1986, SET POINT -26 degrees crank 8 SN = 4

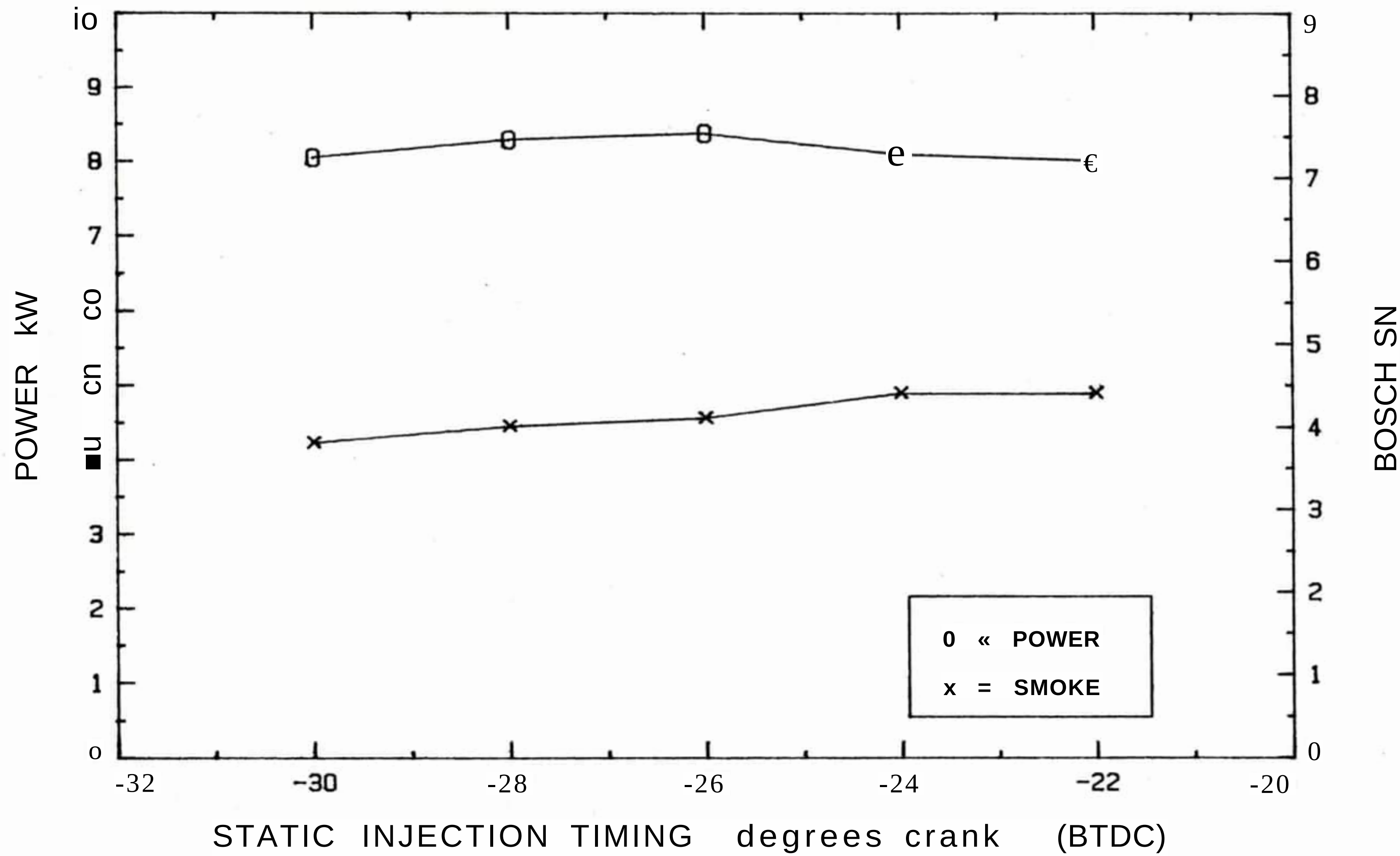

Fig. 16 BRAKE TORQUE & BSFC vs STATIC INJECTION TIMING 75 REV/S

RUN 2, APRIL 3, 1986, SET POINT -28 degrees crank @ SN = 4

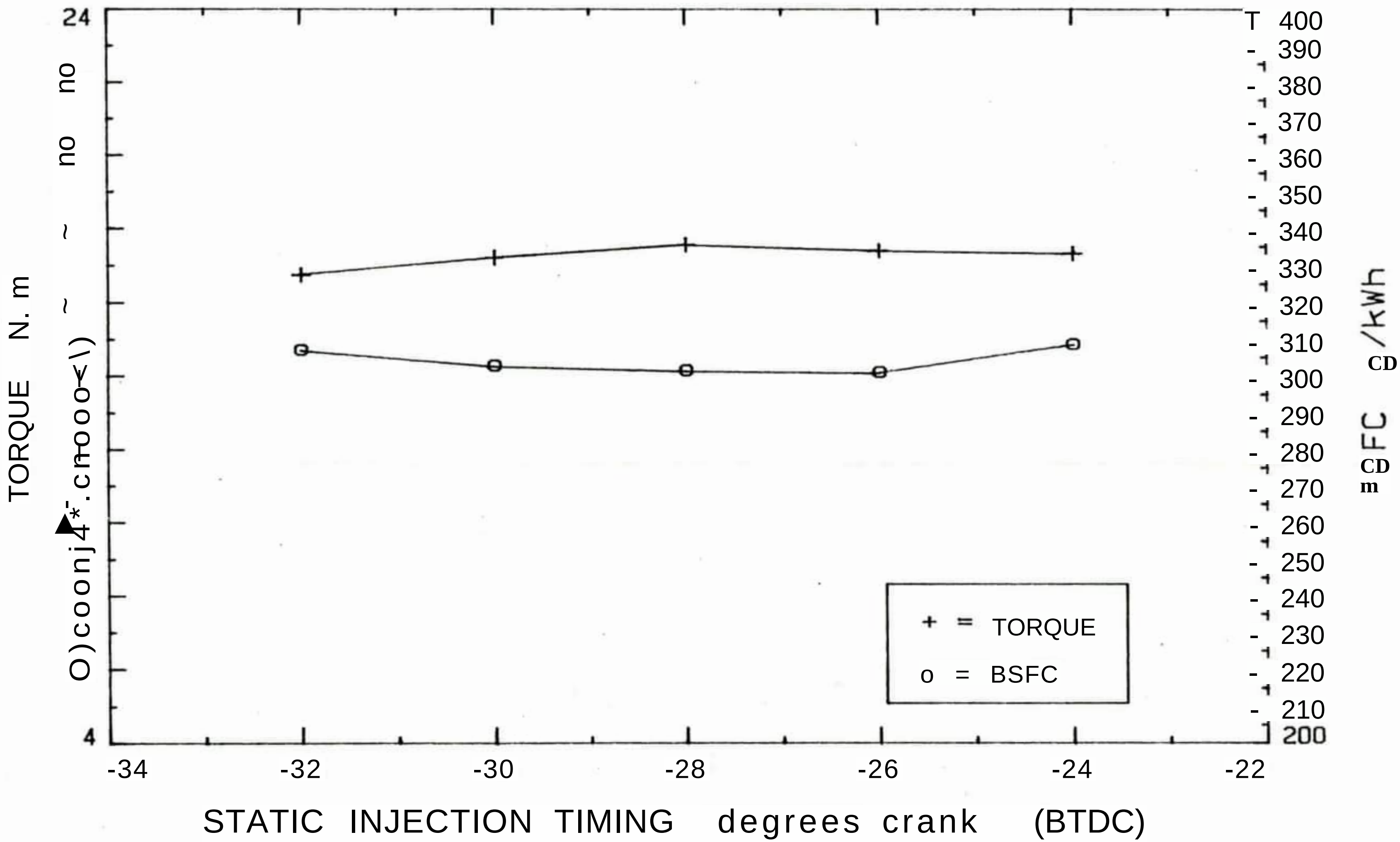

Fig. 17 BRAKE POWER & BOSCH SN vs STATIC INJECTION TIMING 75 REV/S

RUN 2, APRIL 3, 1986, SET POINT -28 degrees crank @ SN = 4

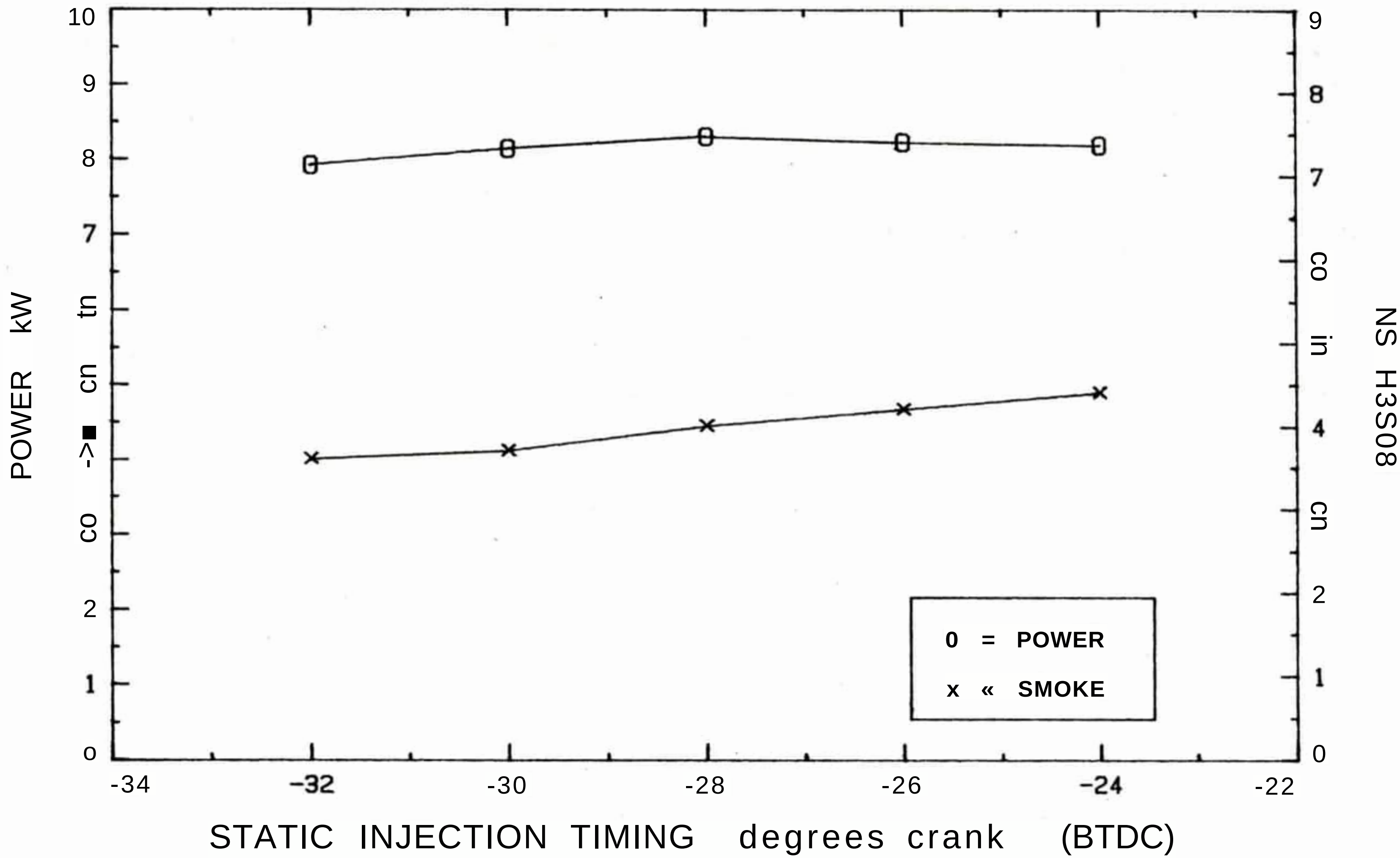

Fig. 18 BRAKE TORQUE & BSFC vs STATIC INJECTION TIMING 40 REV/S

RUN 1, APRIL 10, 1986, SET POINT -15 degrees crank @ 7. 16 N. m

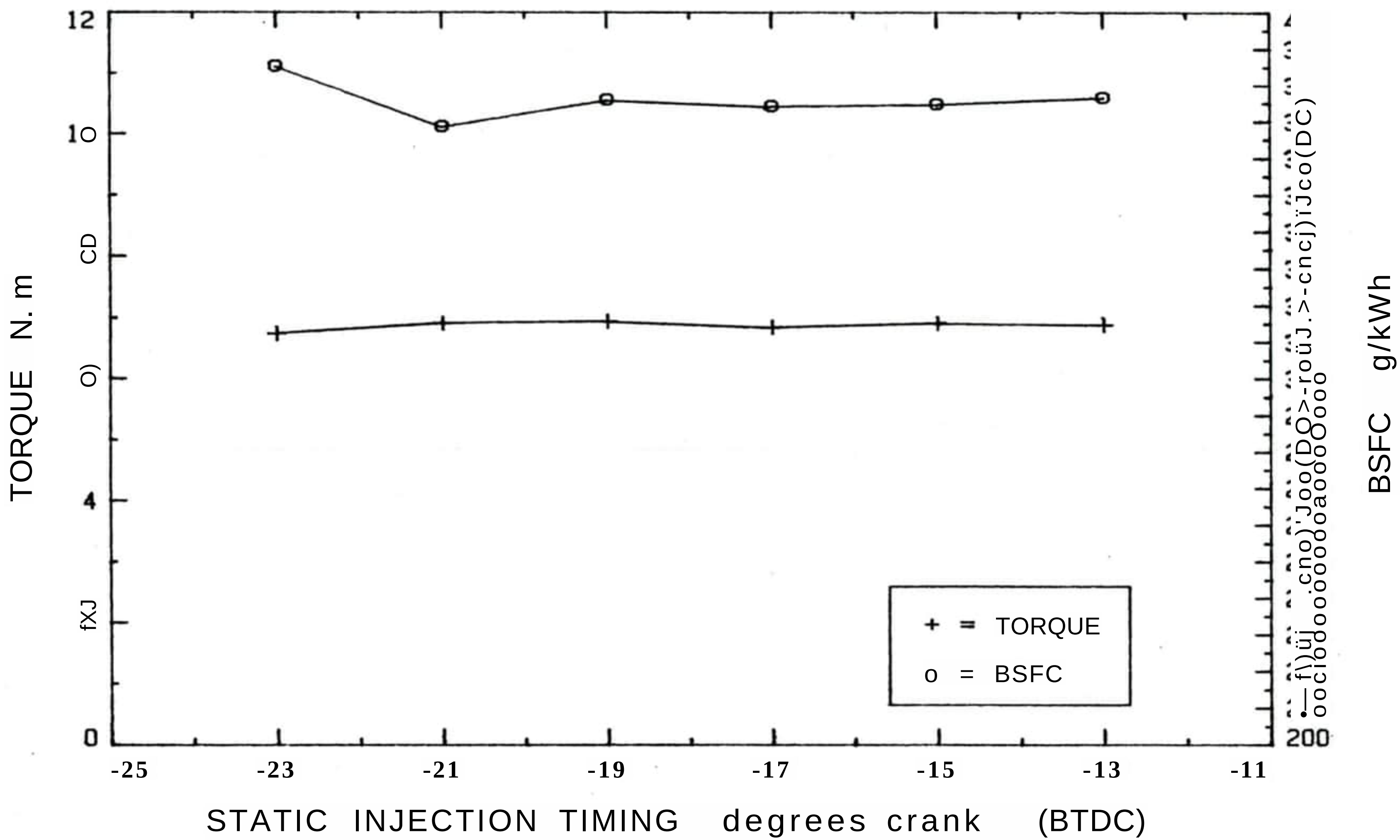

Fig. 19 BRAKE POWER & BOSCH SN vs STATIC INJECTION TIMING 40 REV/S

RUN 1, APRIL 10, 1986, SET POINT -15 degrees crank @ 7.16 N.m

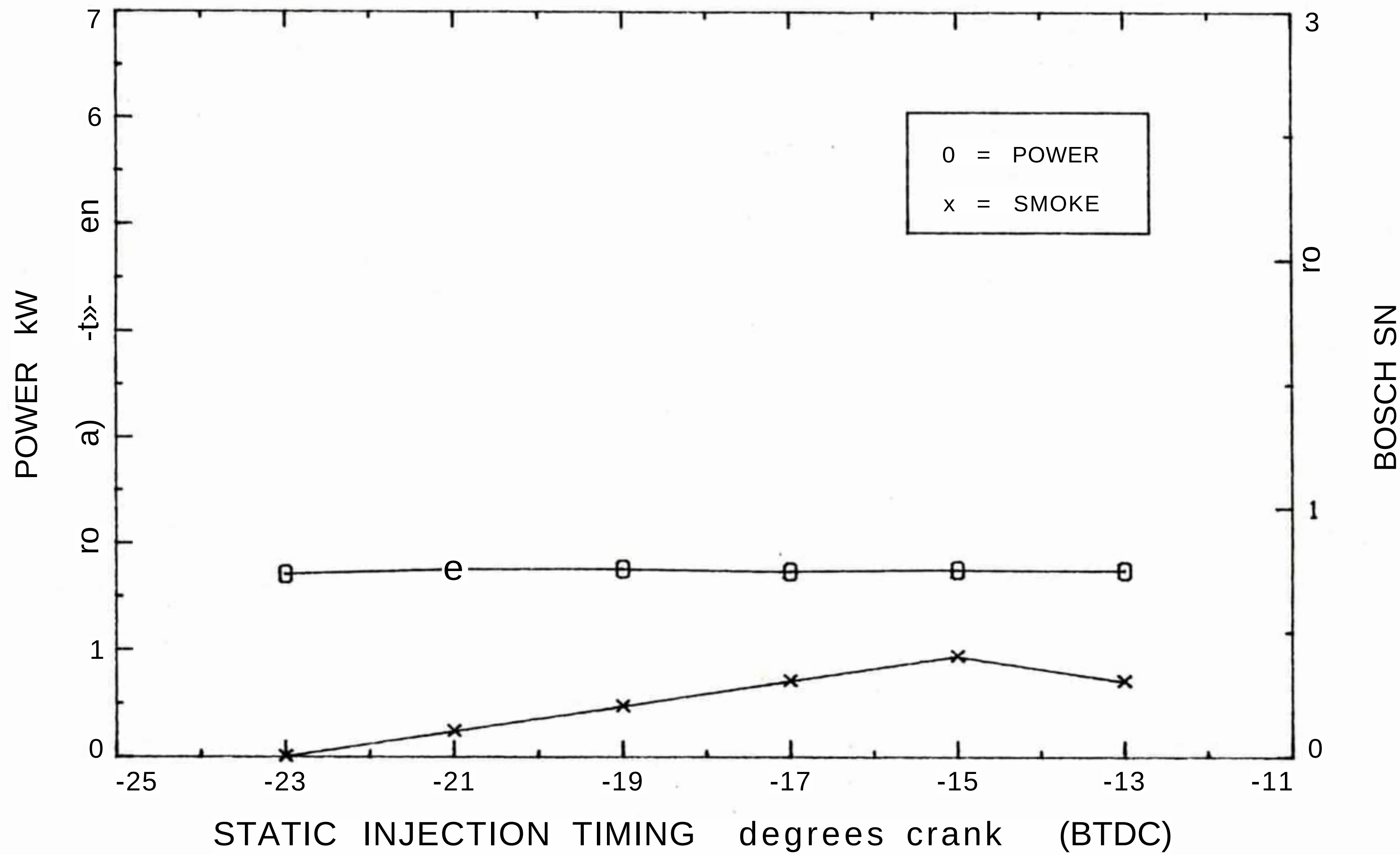

Fig. 2() BRAKE TORQUE & BSFC vs STATIC INJECTION TIMING 40 REV/S

2, APRIL 10, 1986, SET POINT -15 degrees crank @ 14. 32 N. m

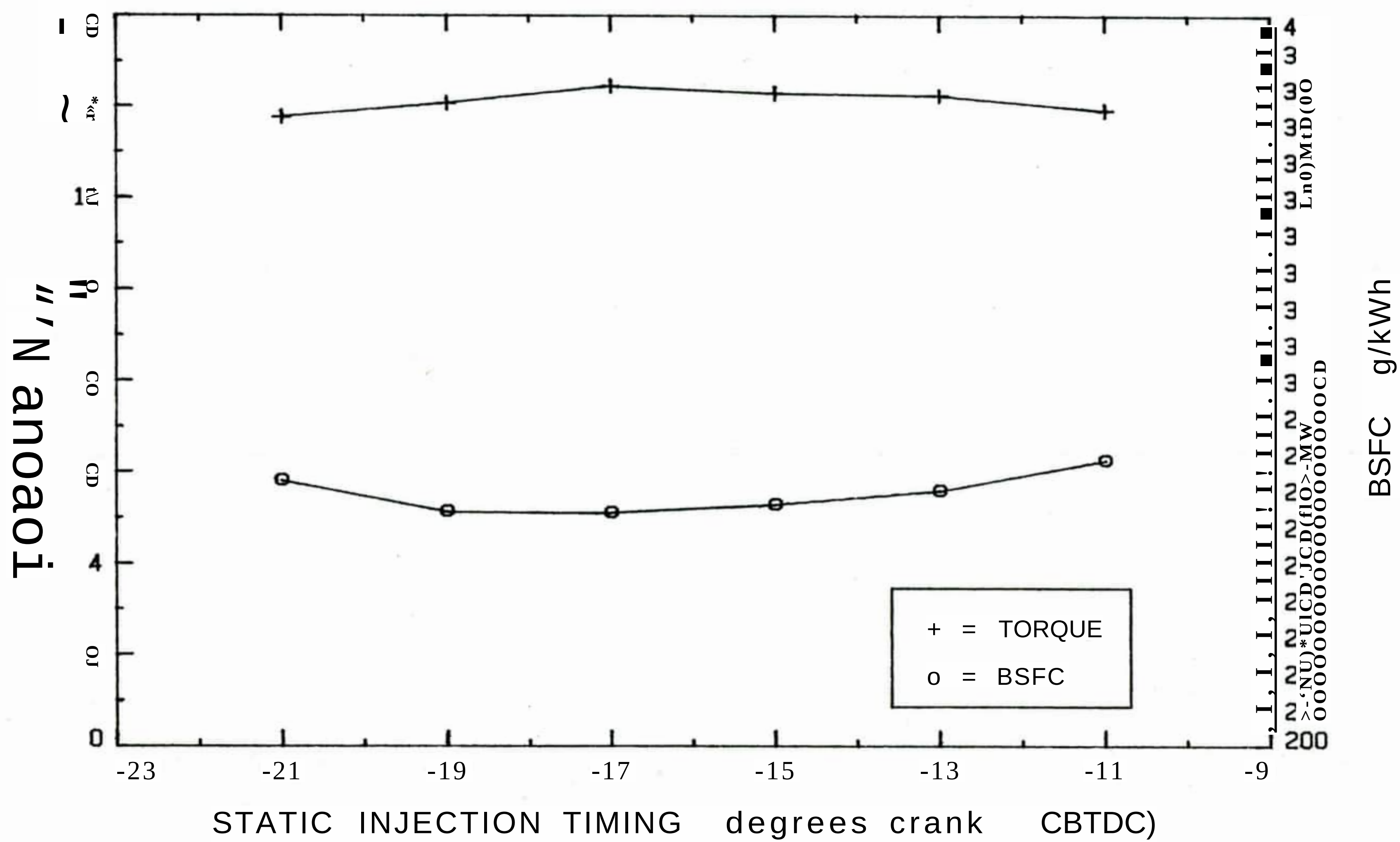

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Fig. 21 BRAKE POWER & BOSCH SN vs STATIC INJECTION TIMING 40 REV/S

RUN 2, APRIL 10, 1986, SET POINT -15 degrees crank @ 14.32 N. m

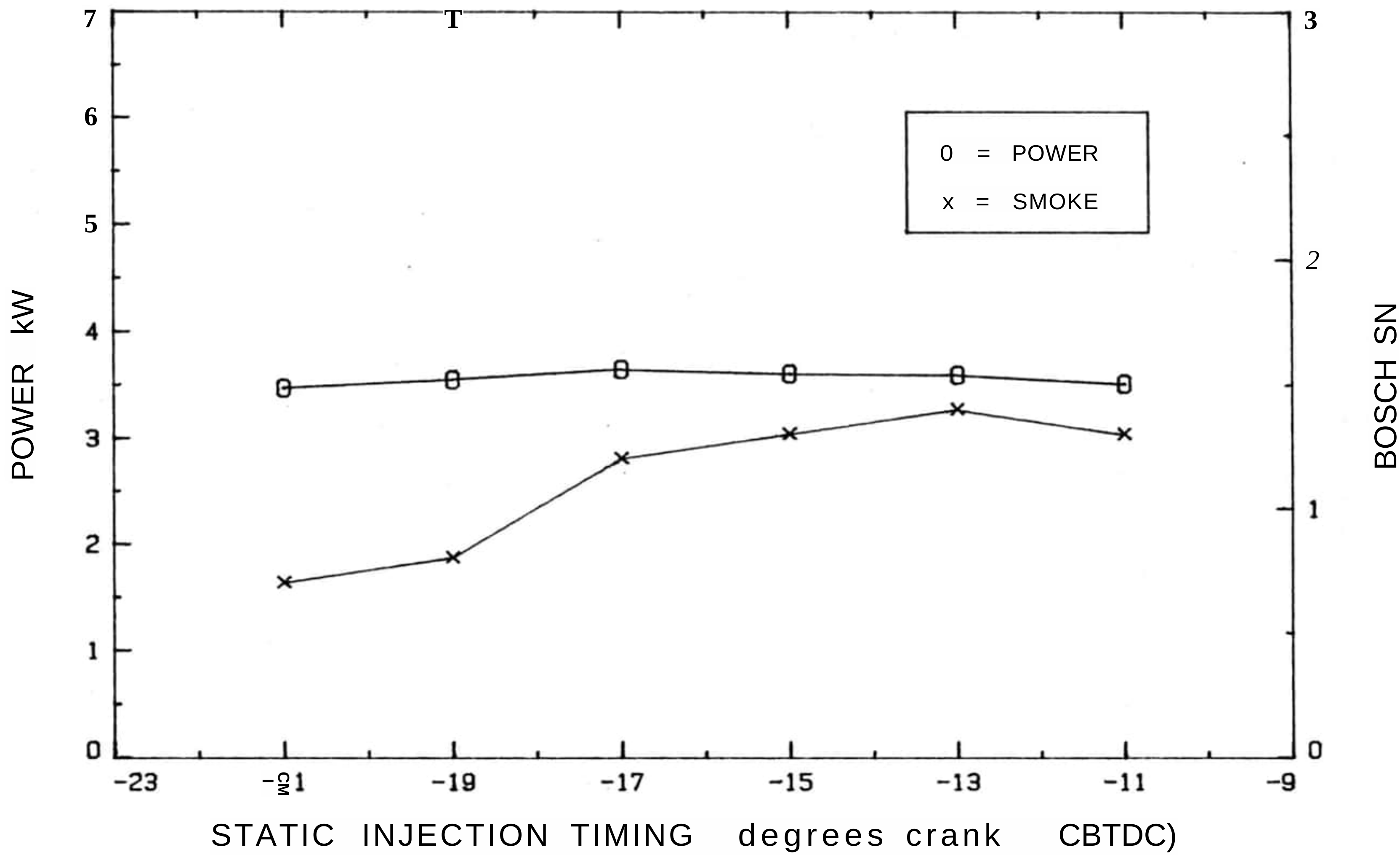

Fig. 22 BRAKE TORQUE & BSFC vs STATIC INJECTION TIMING 65 REV/S

RUN 1, APRIL 17, 1986, SET POINT -24 degrees crank @ 7. 16 N. m

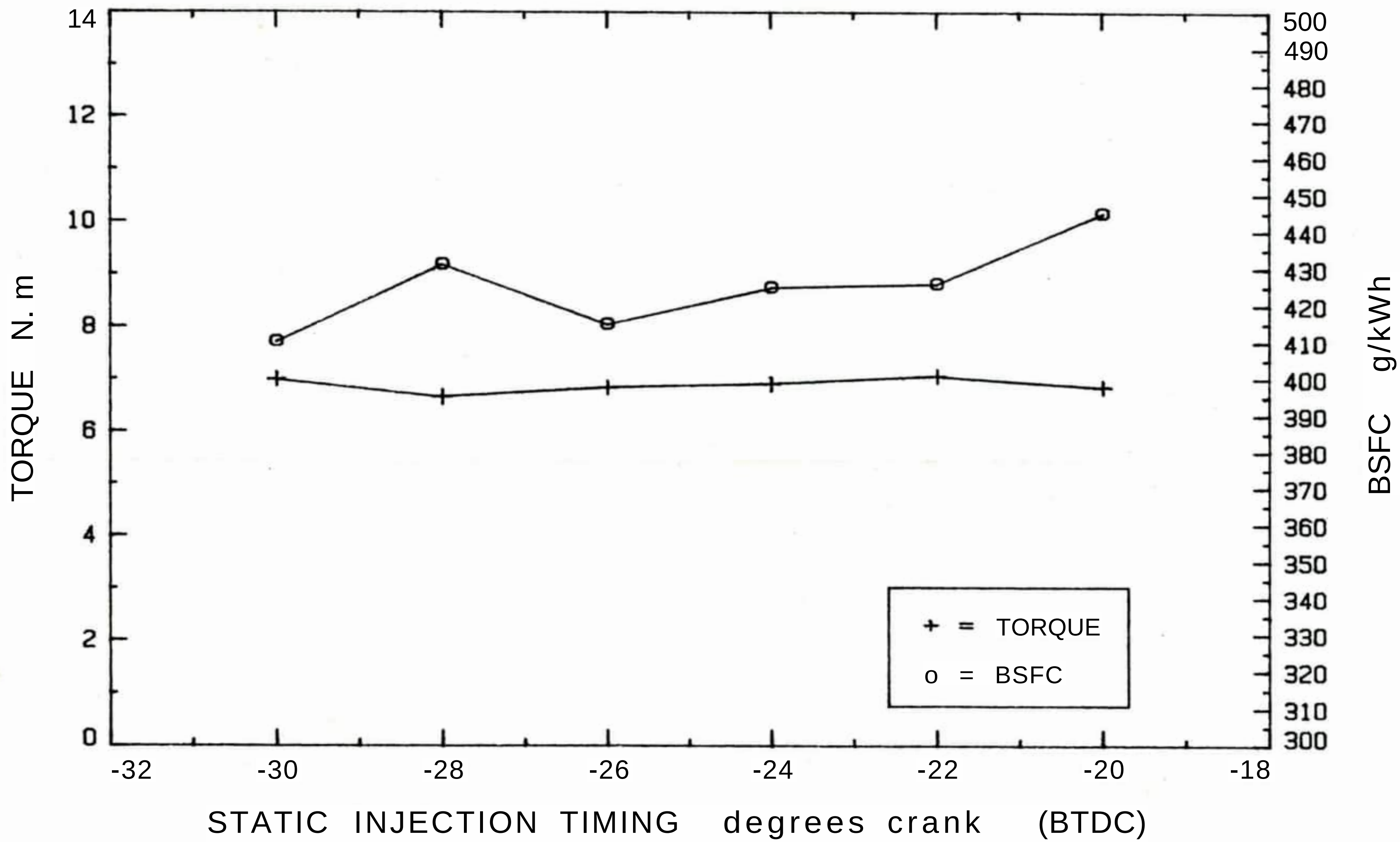

Fig. 23 BRAKE POWER & BOSCH SN vs STATIC INJECTION TIMING 65 REV/S

RUN 1, APRIL 17, 1986» SET POINT -24 degrees crank 6 7. 16 N. m

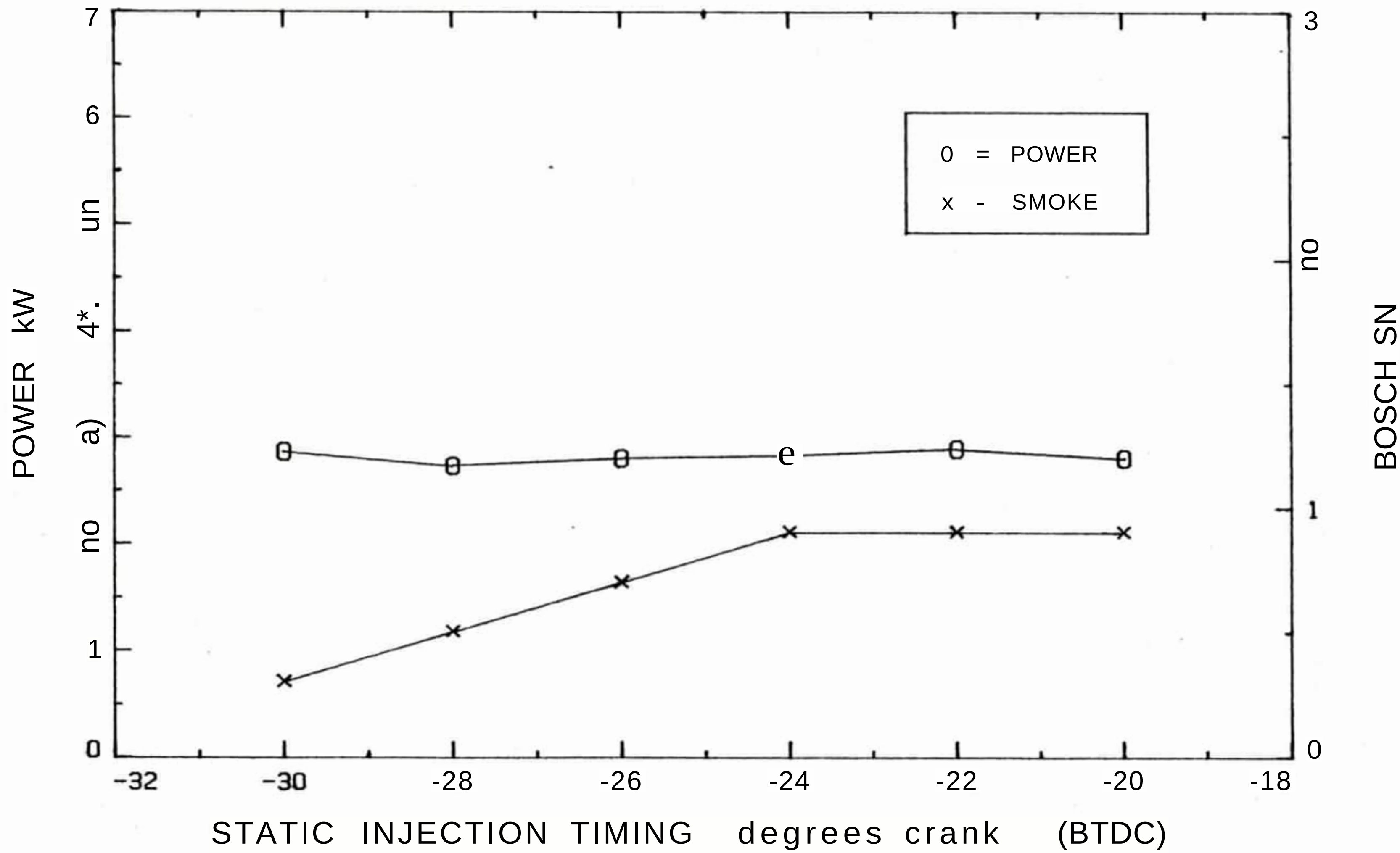

Fig. 24 BRAKE TORQUE & BSFC vs STATIC INJECTION TIMING 65 REV/S

RUN 2: APRIL 17, 1986, SET POINT -24 degrees crank @ 14.32 N.m

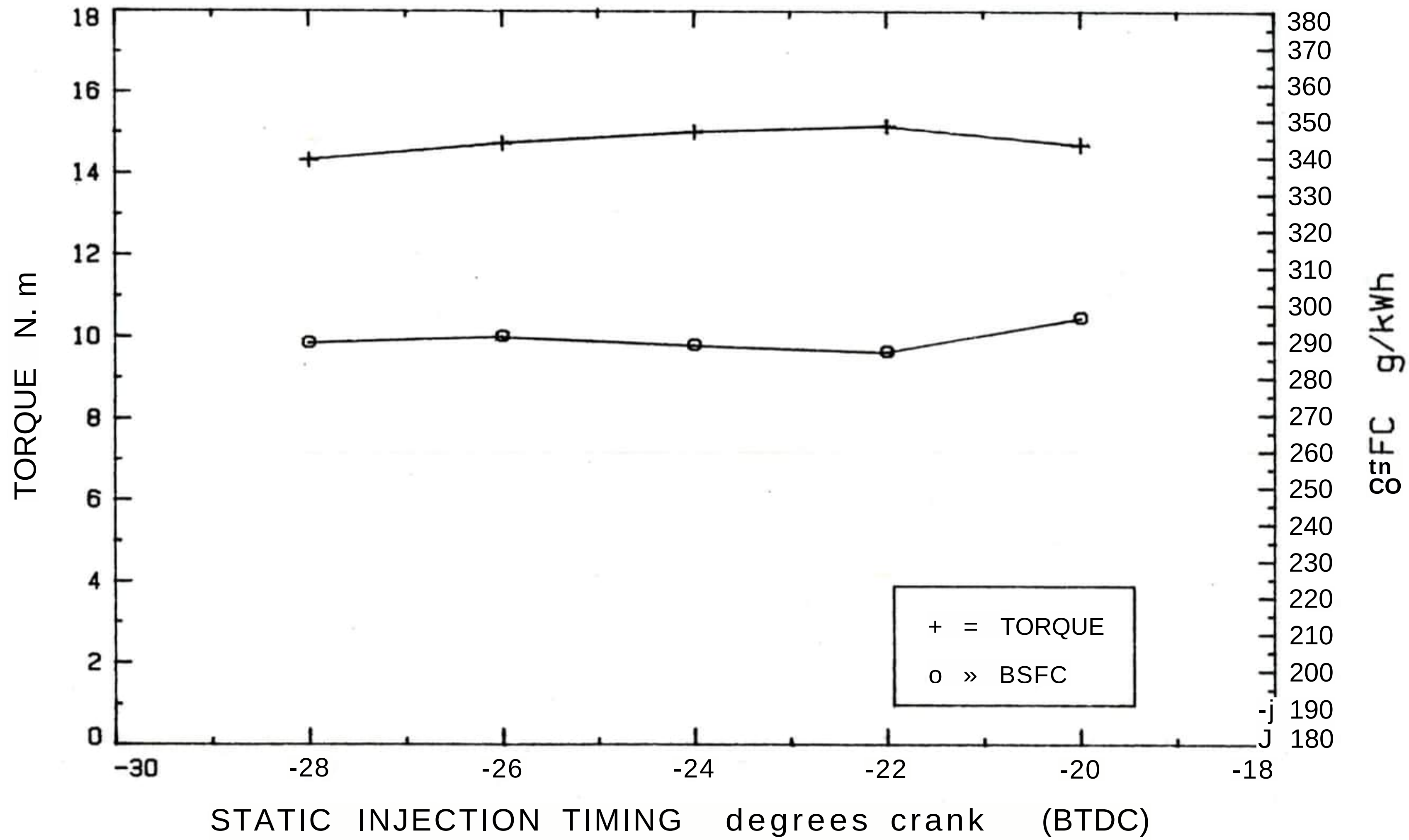

Fig. 25 BRAKE POWER & BOSCH SN vs STATIC INJECTION TIMING 65 REV/S

RUN 2, APRIL 17, 1986, SET POINT -24 degrees crank @ 14.32 N.m

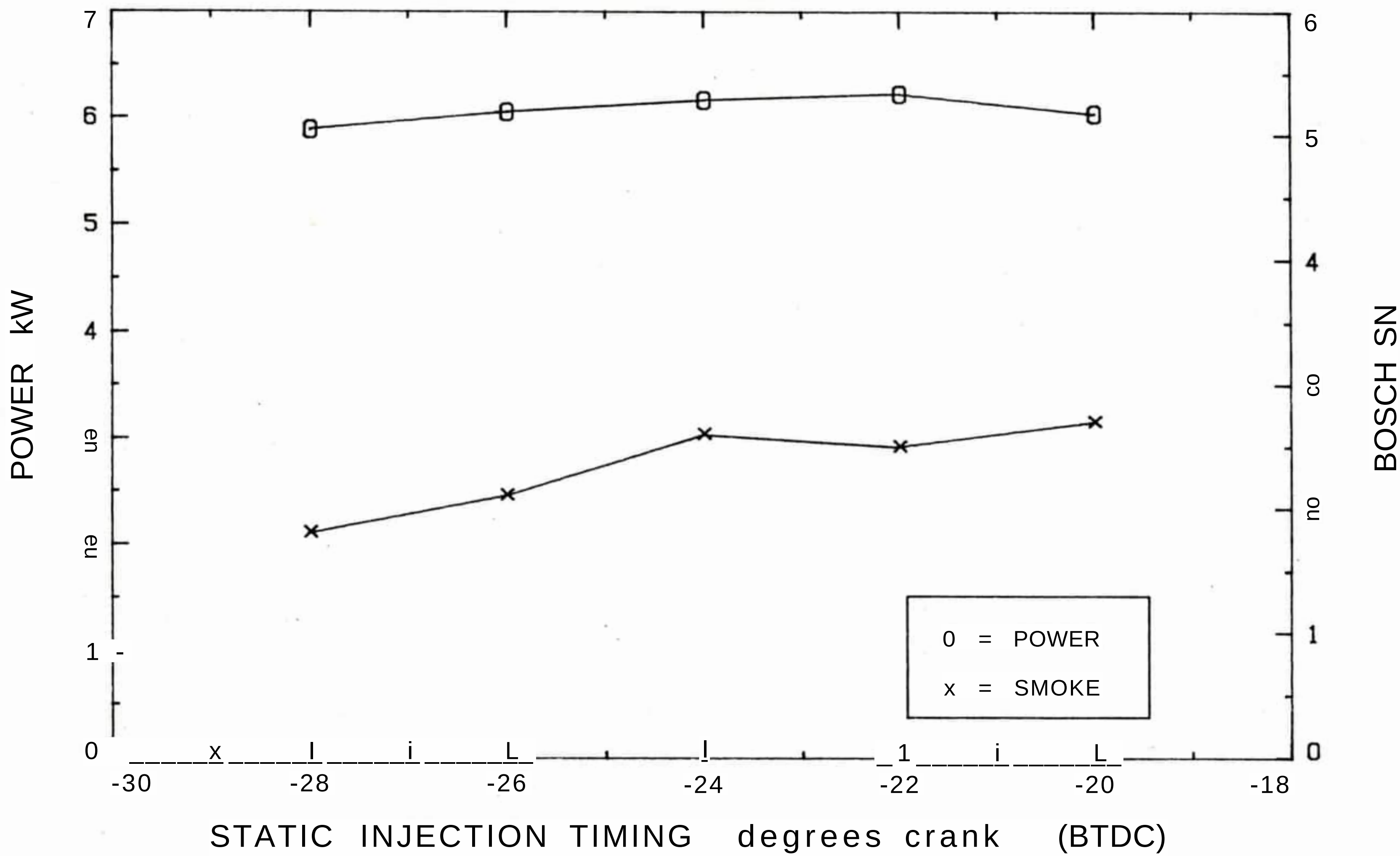

Fig. 26 BRAKE TORQUE & BSFC vs STATIC INJECTION TIMING 75 REV/S

RUN 3, APRIL 18, 1986, SET POINT -28 degrees crank @ 7.16 N.m

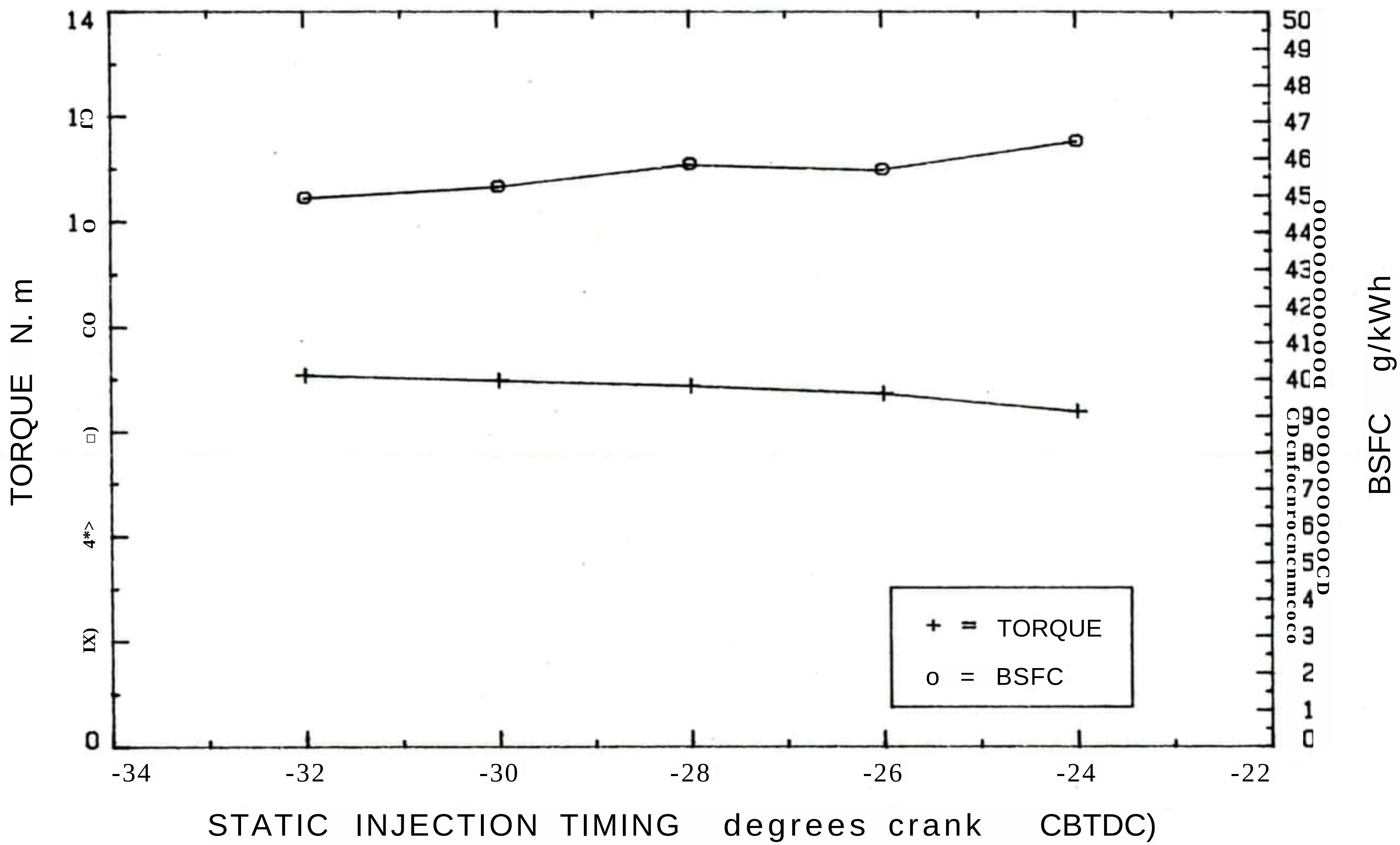

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Fig. 27 BRAKE POWER & BOSCH SN vs STATIC INJECTION TIMING 75 REV/S

RUN 3, APRIL 18, 1986, SET POINT -28 degrees crank @ 7. 16 N. m

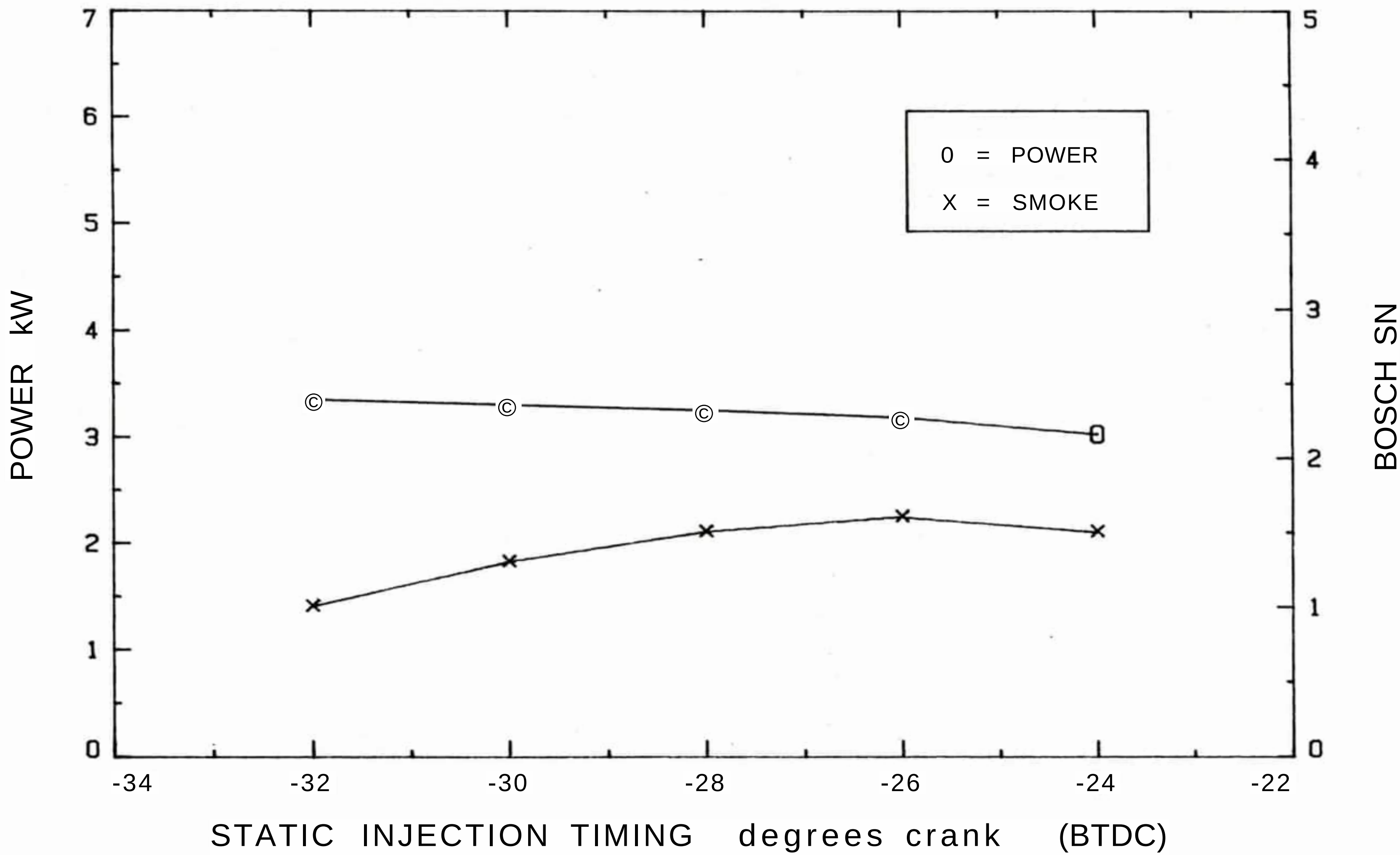

FIG.28 30 REV/S SN=4 -16 DEG CR

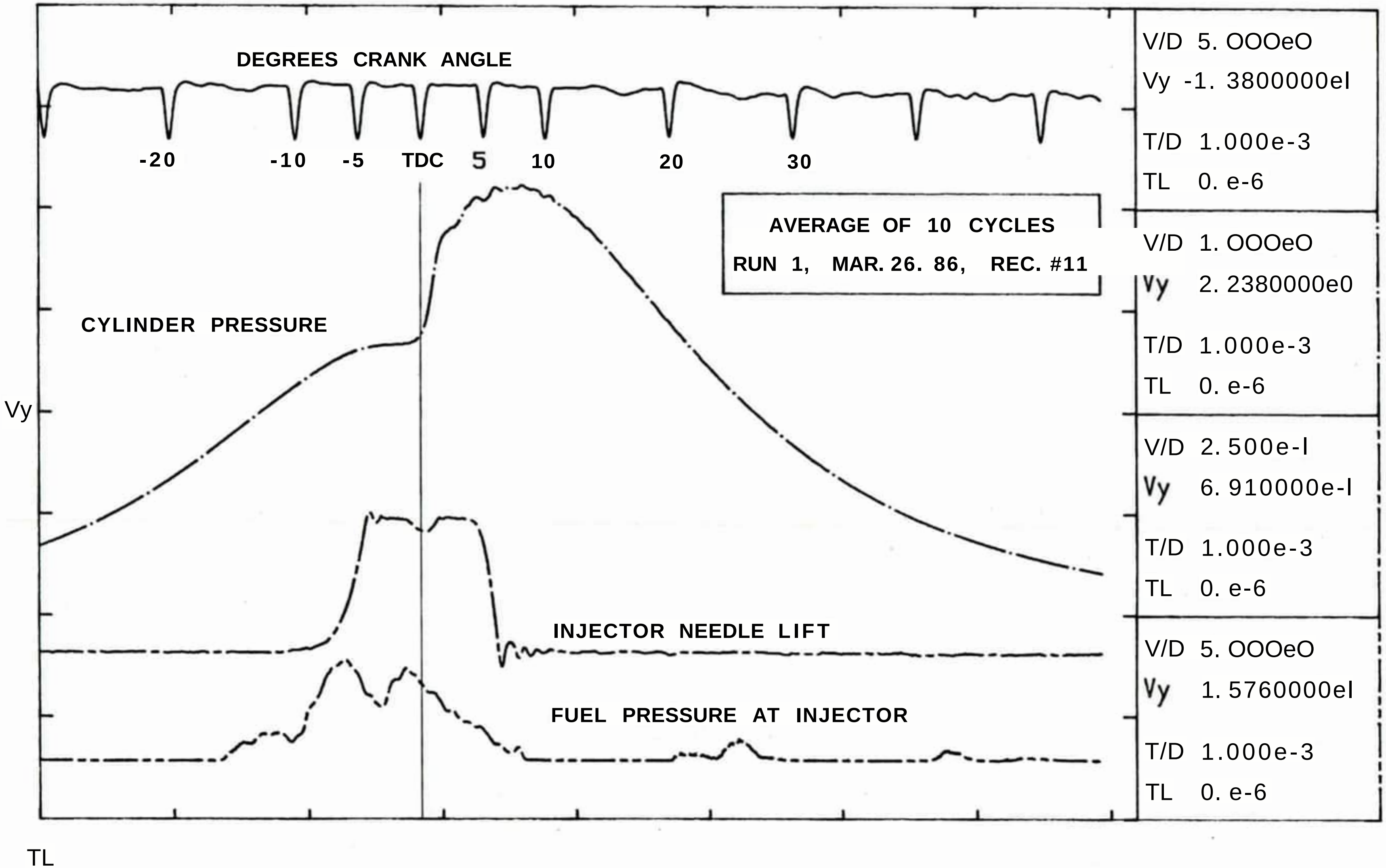

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FIG. 29 40 REV/S SN=4 -17 DEG CR

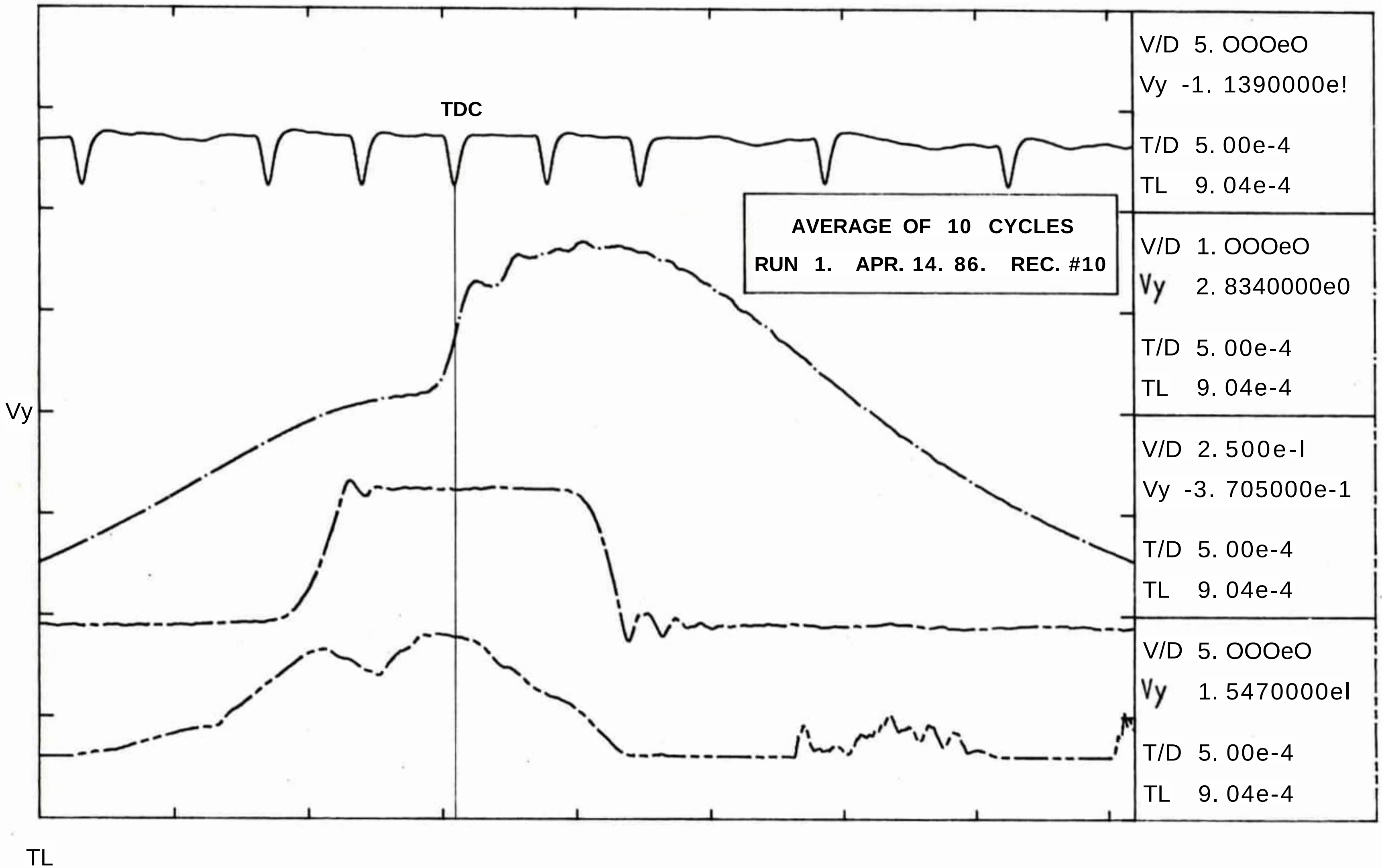


FIG-30 40 REV/S SN=4 -19 DEG CR

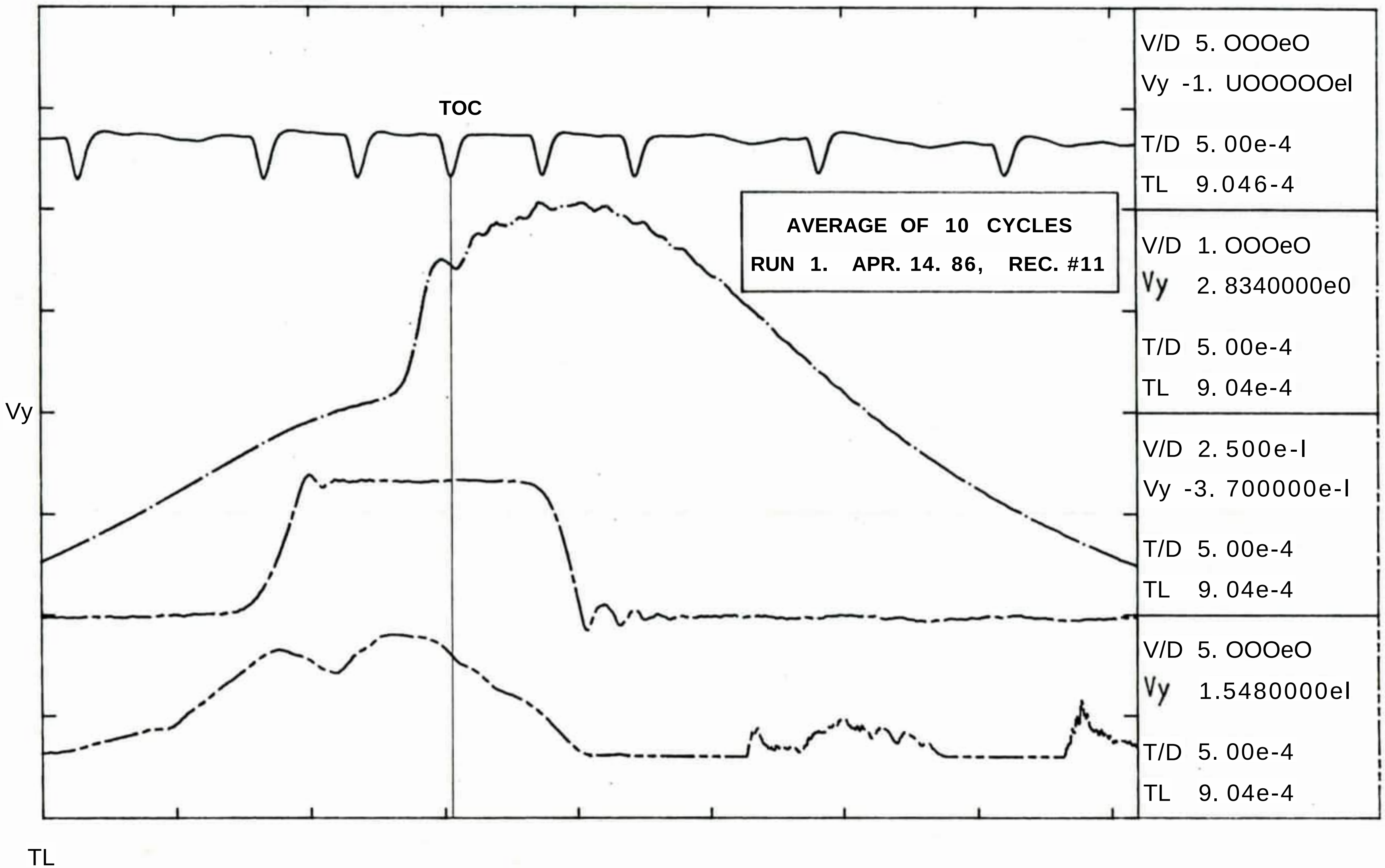


FIG. 31 50 REV/S SN=4 -19 DEG OR

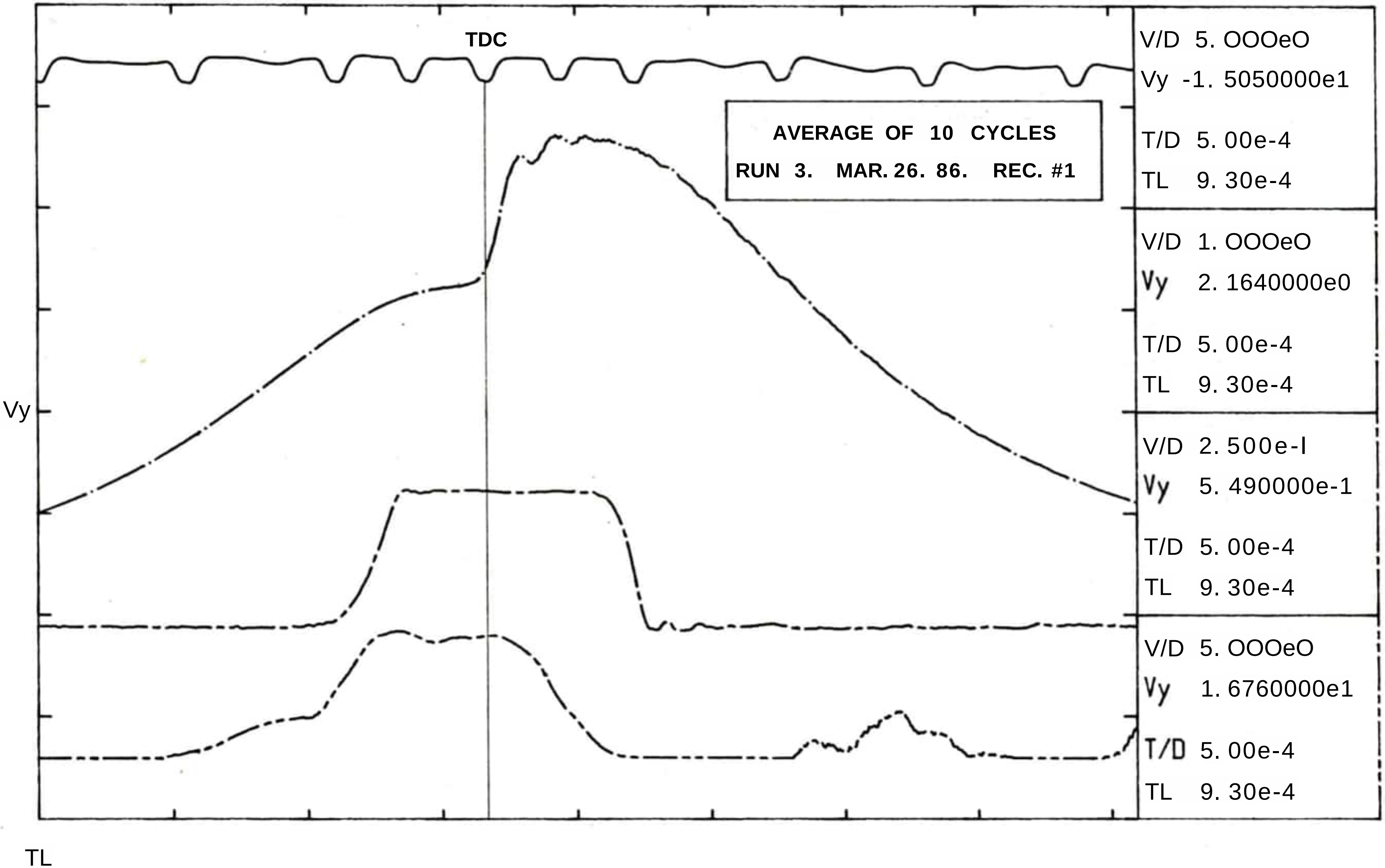
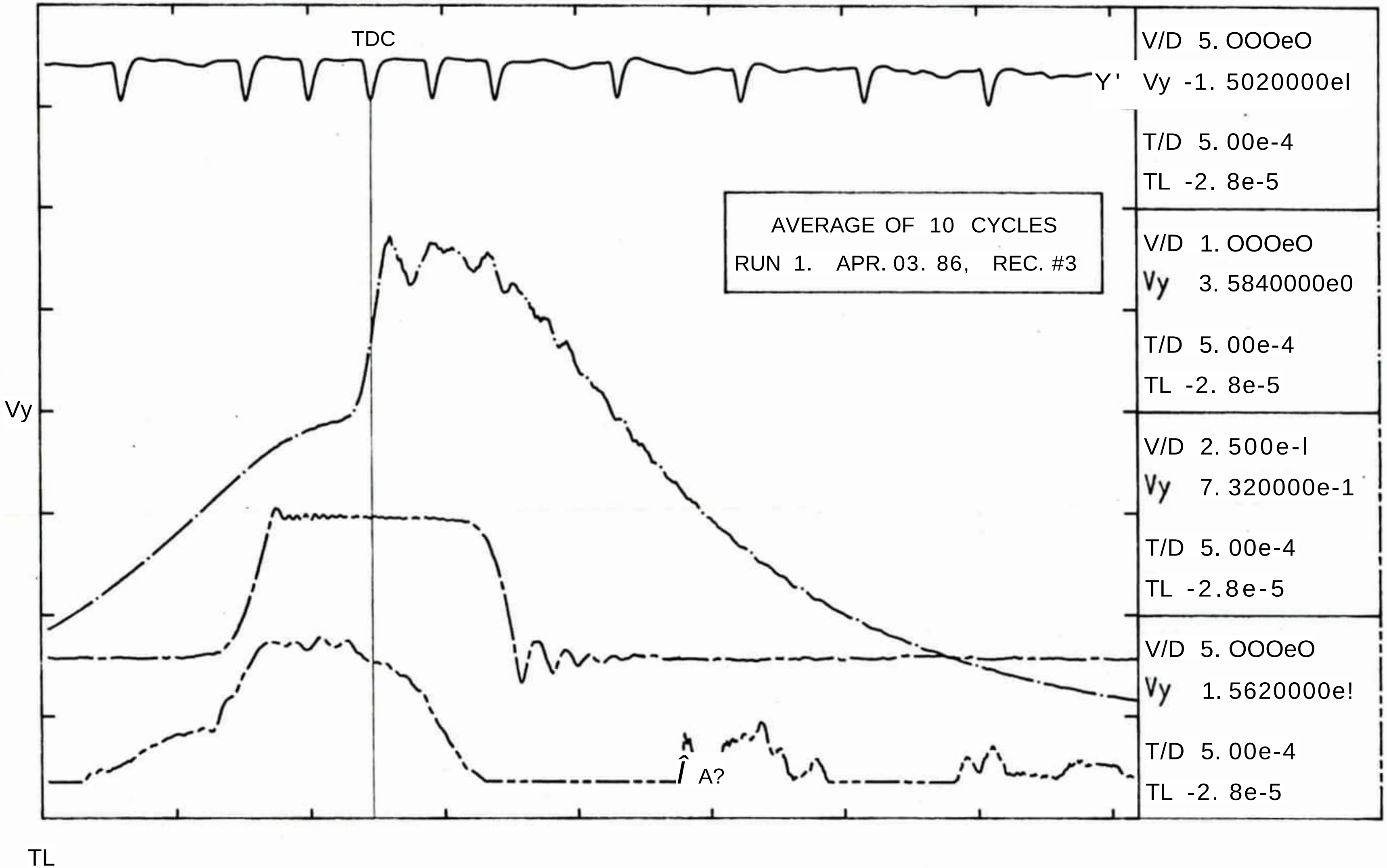


FIG. 32 60 REV/S SN=4 -22 DEG CR



FIG» 33   60 REV/S SN=4 -18 DEG CR

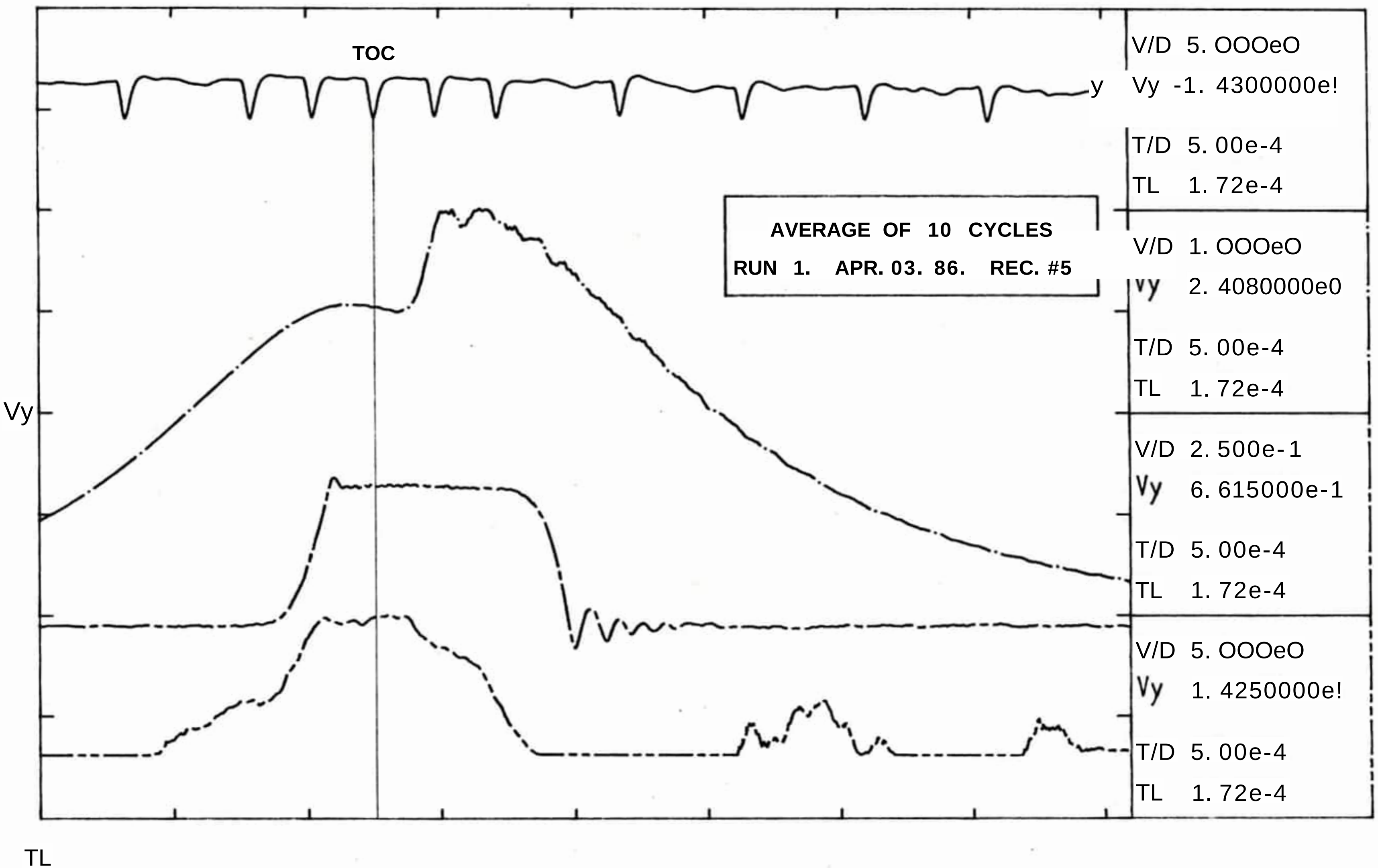


FIG. 34 60 REV/S SN=4 -20 DEG CR

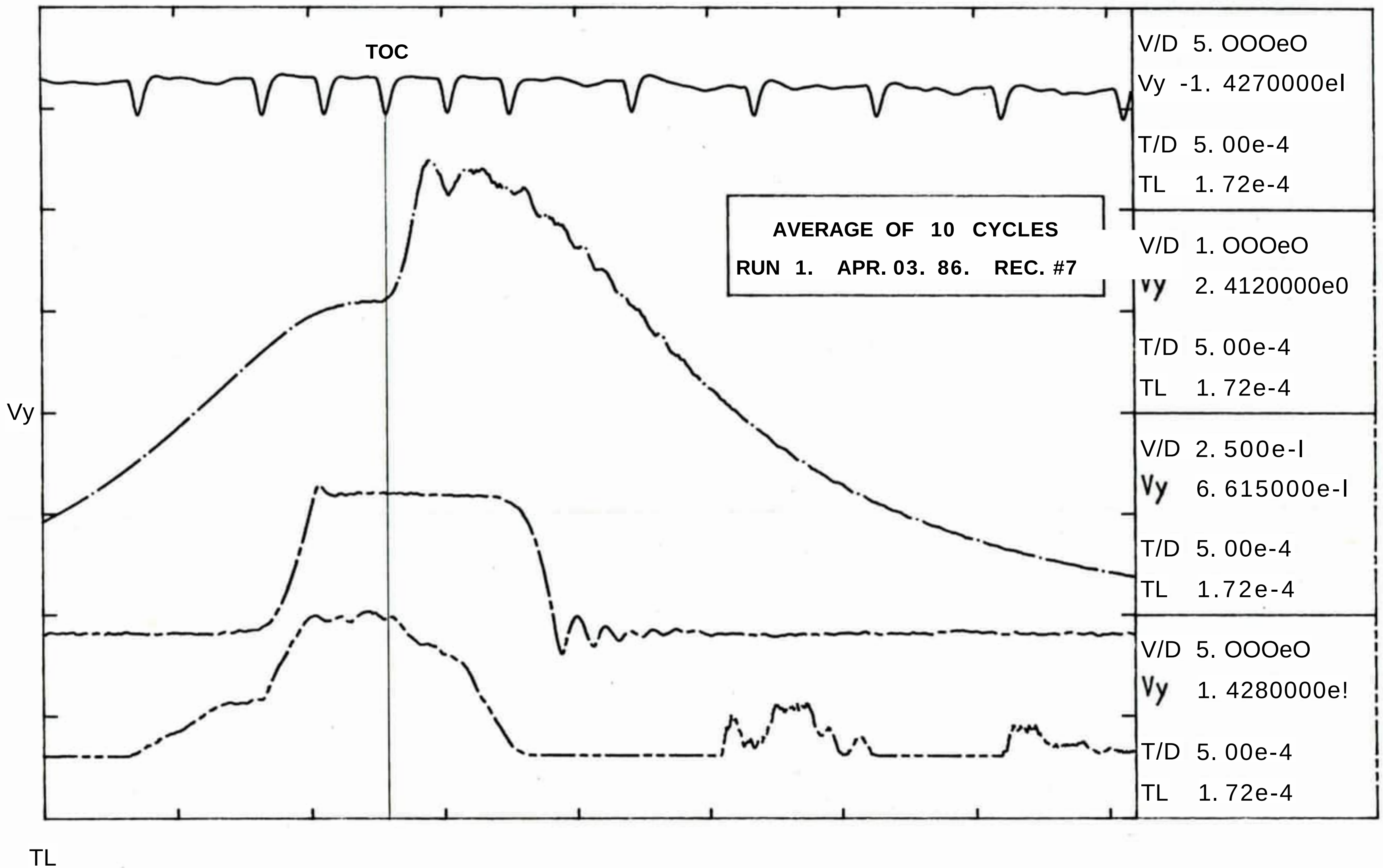


FIG. 35 60 REV/S SN=4 -22 DEG CR

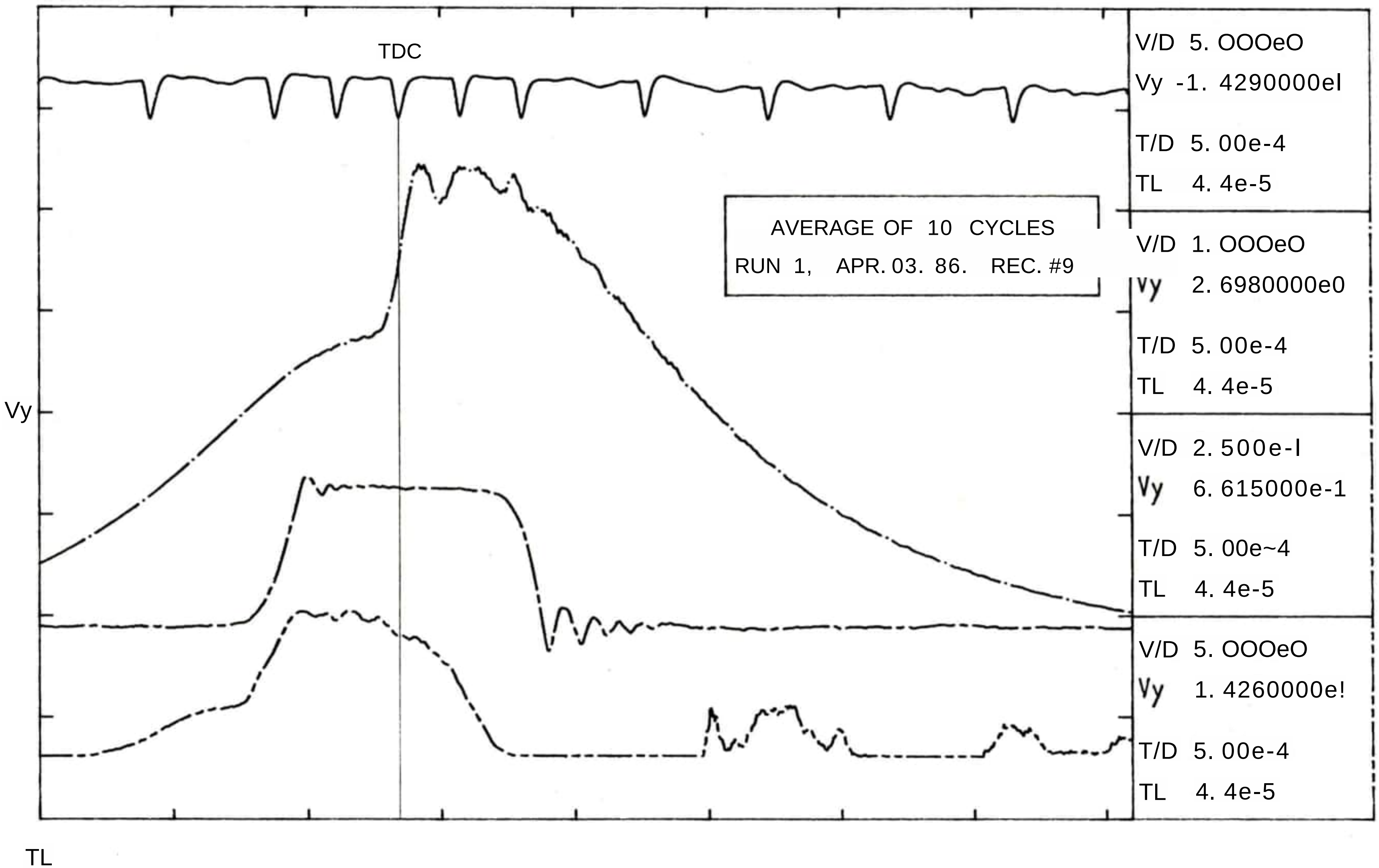


FIG. 36 60 REV/S SN=4 -24 DEG OR

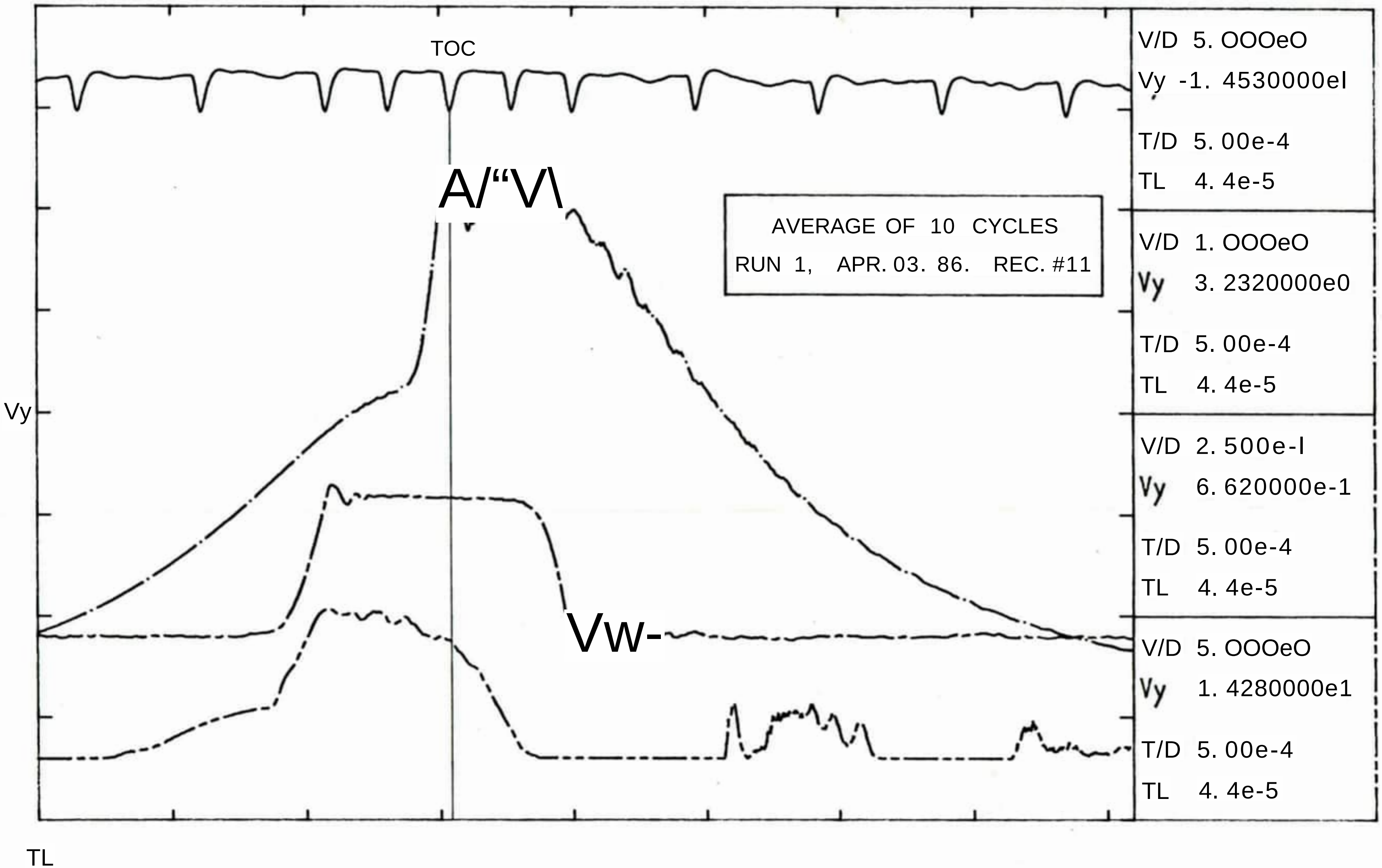


FIG. 37 60 REV/S SN=4 -26 DEG CR

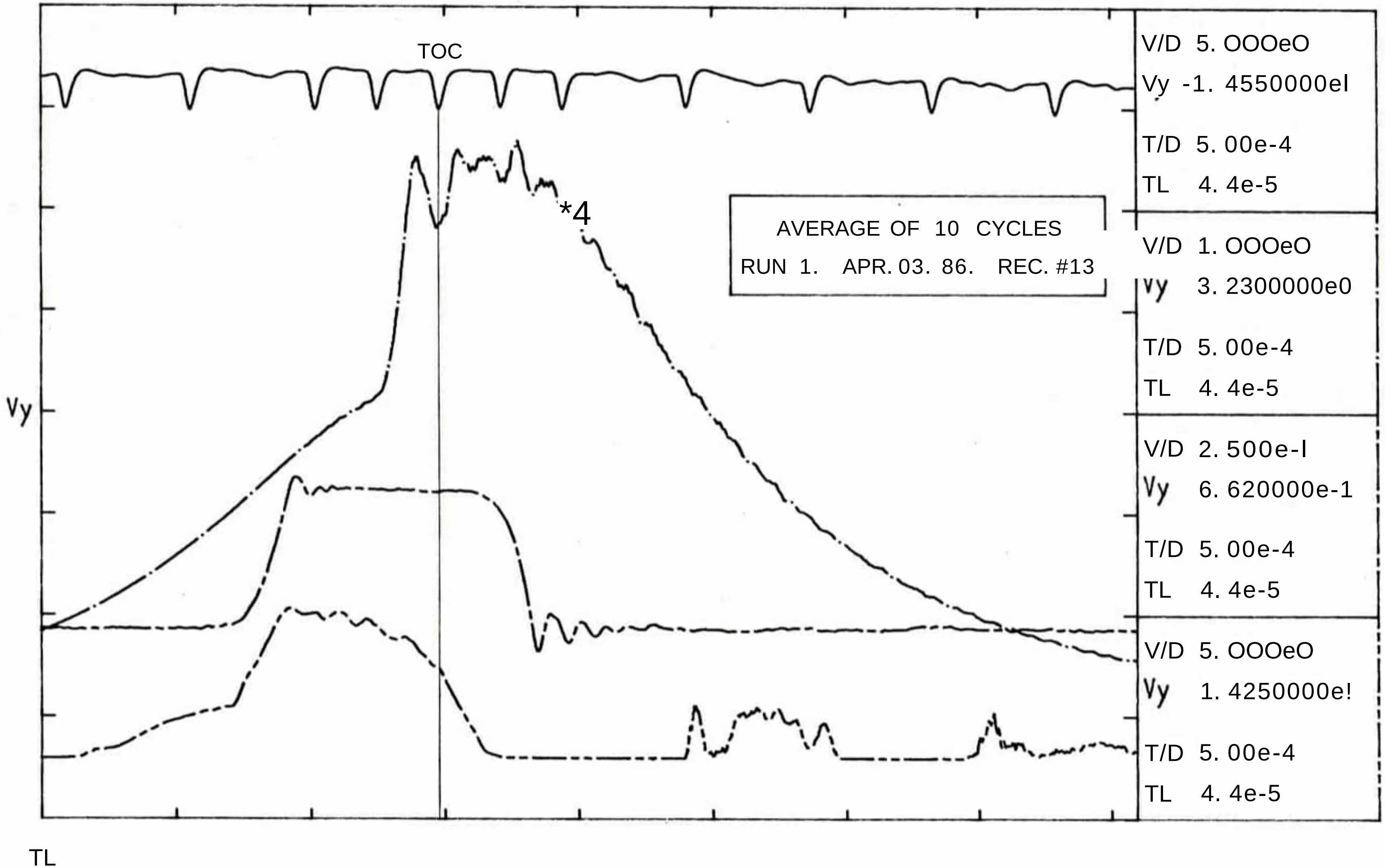


FIG. 38 60 REV/S SN=4 -22 DEG CR

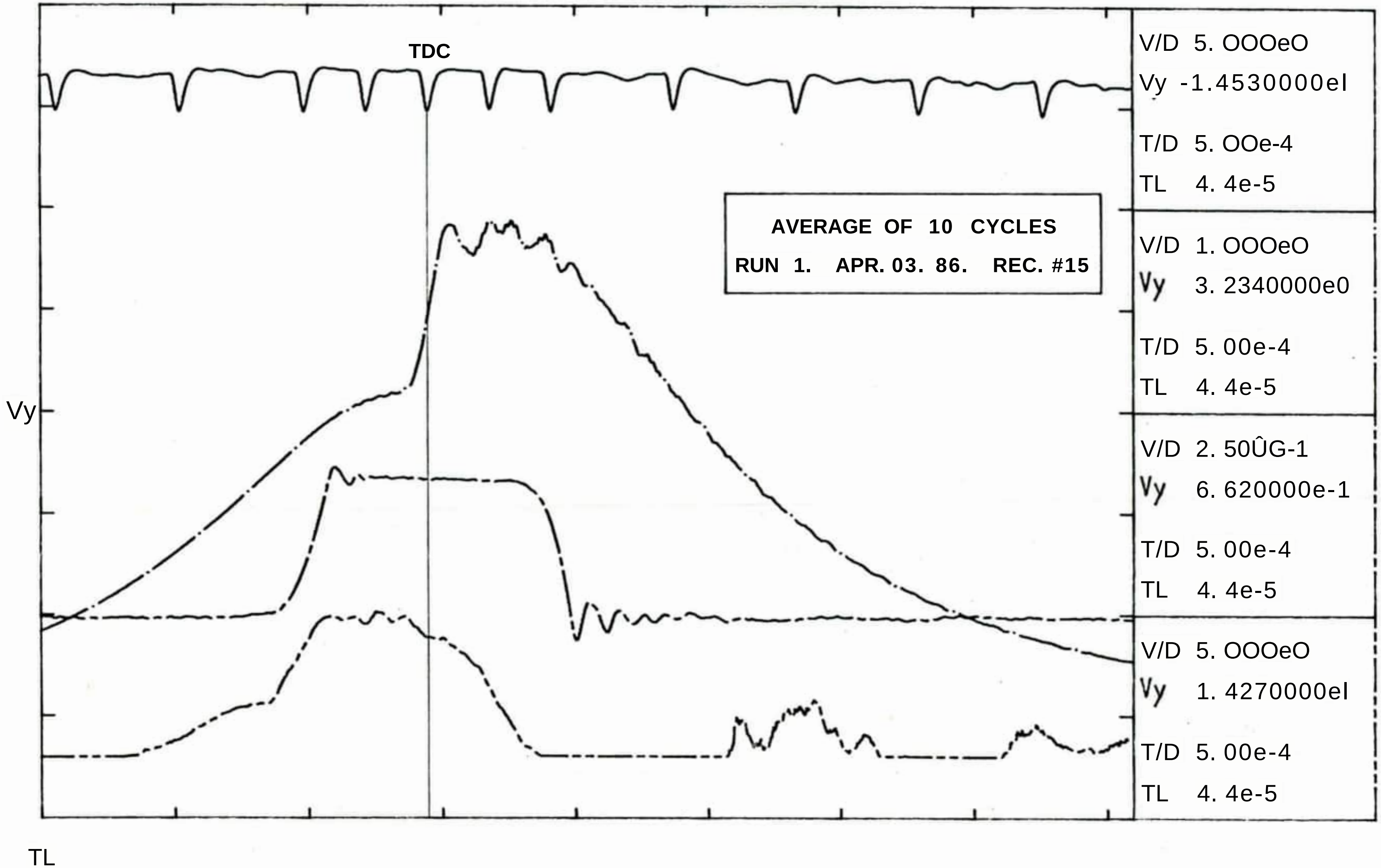


FIG. 39 65 REV/S SN=4 -24 DEG CR

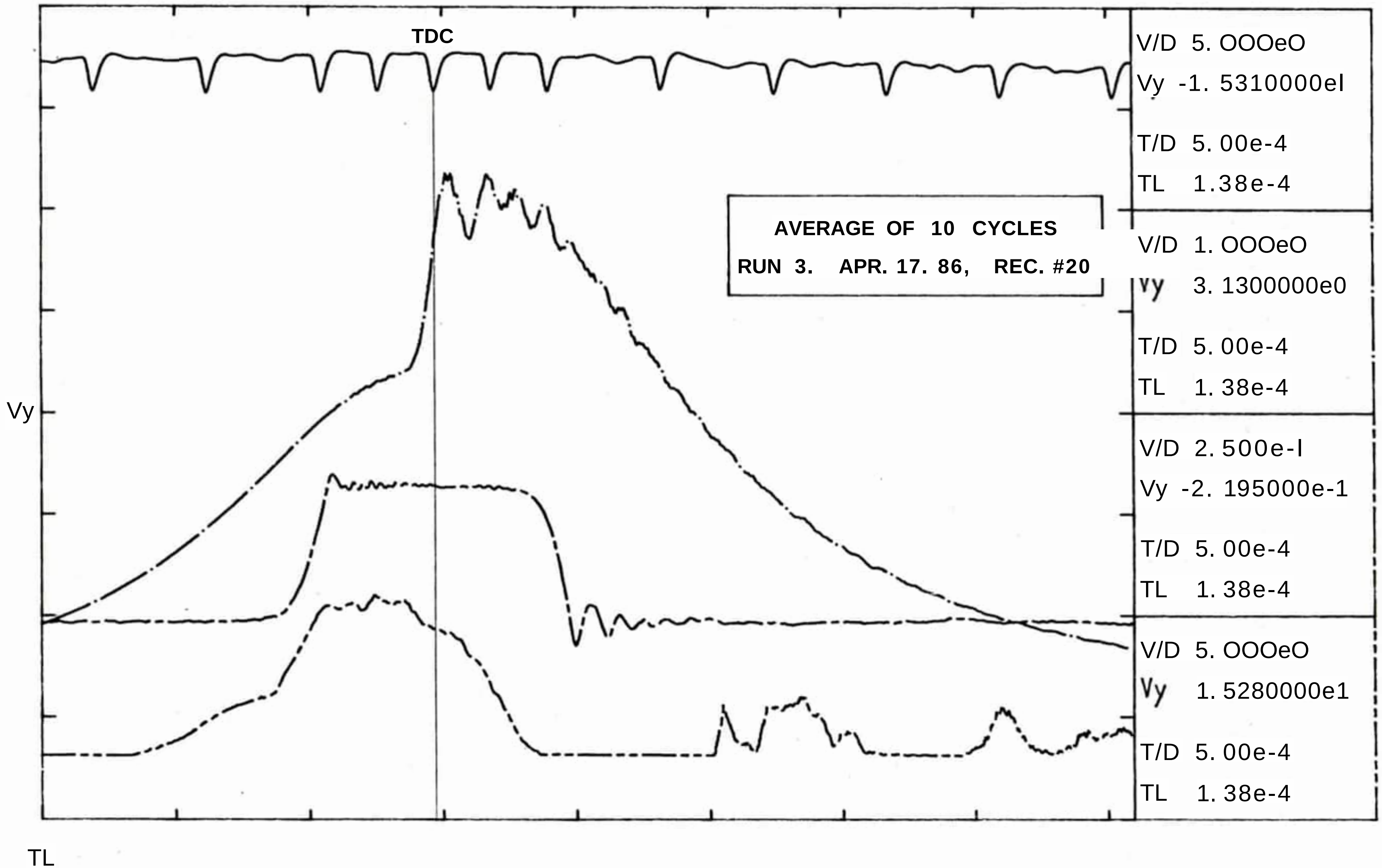


FIG. 40 70 REV/S SN=4 -26 DEG CR

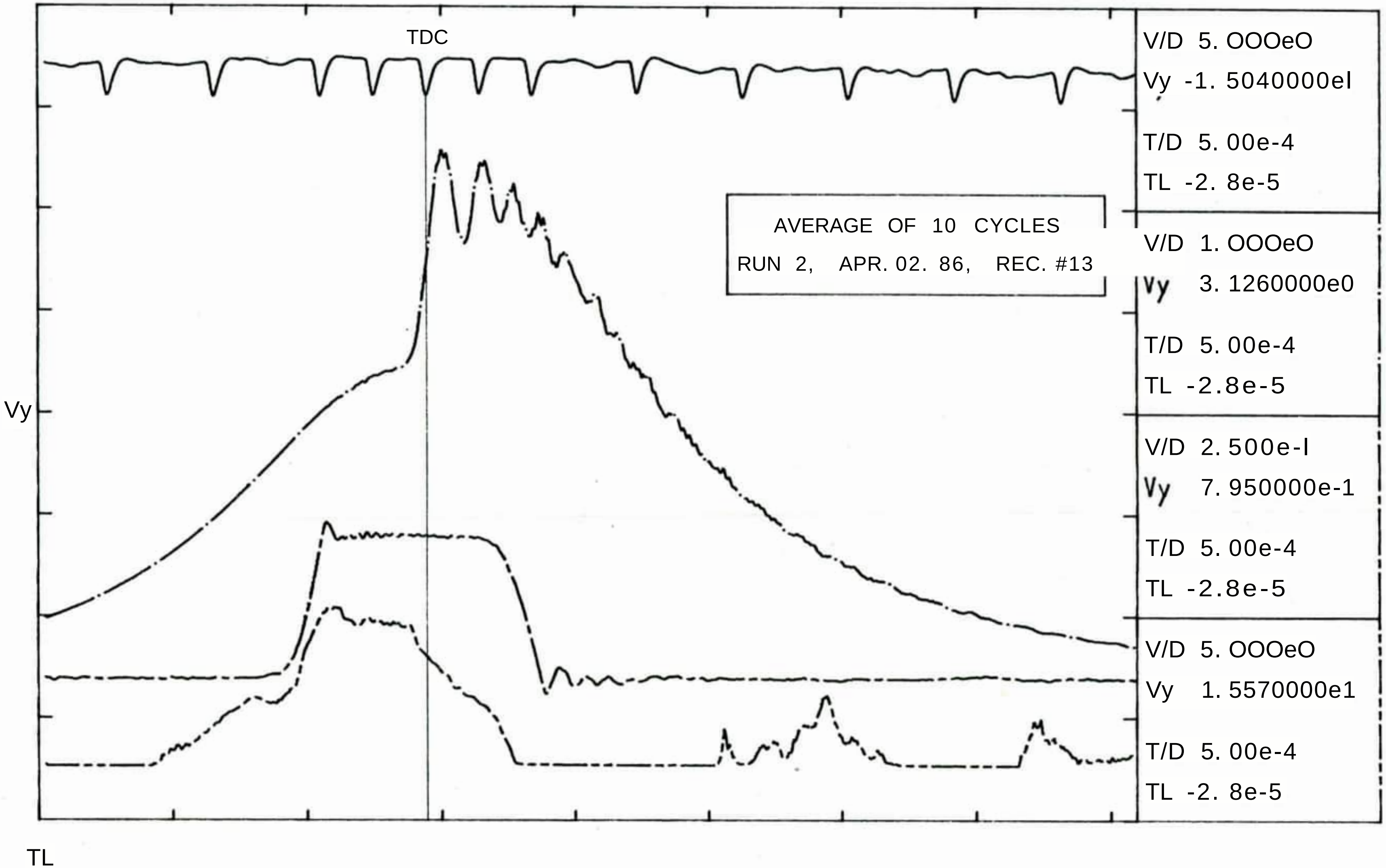


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FIG. 41 75 REV/S SN=4 -28 DEG CR

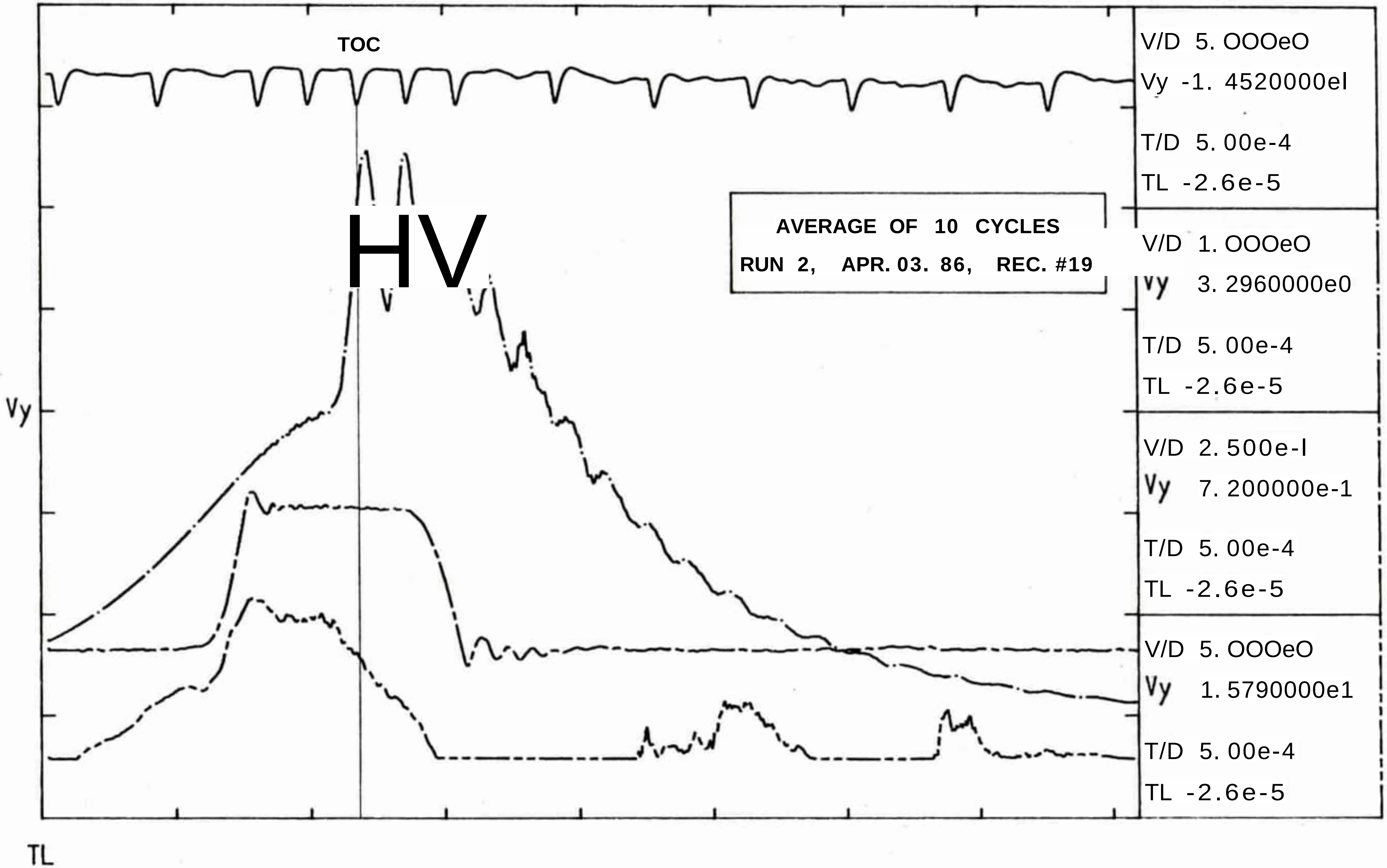

FIG. 42 75 REV/S SN=4 -24 DEG CR

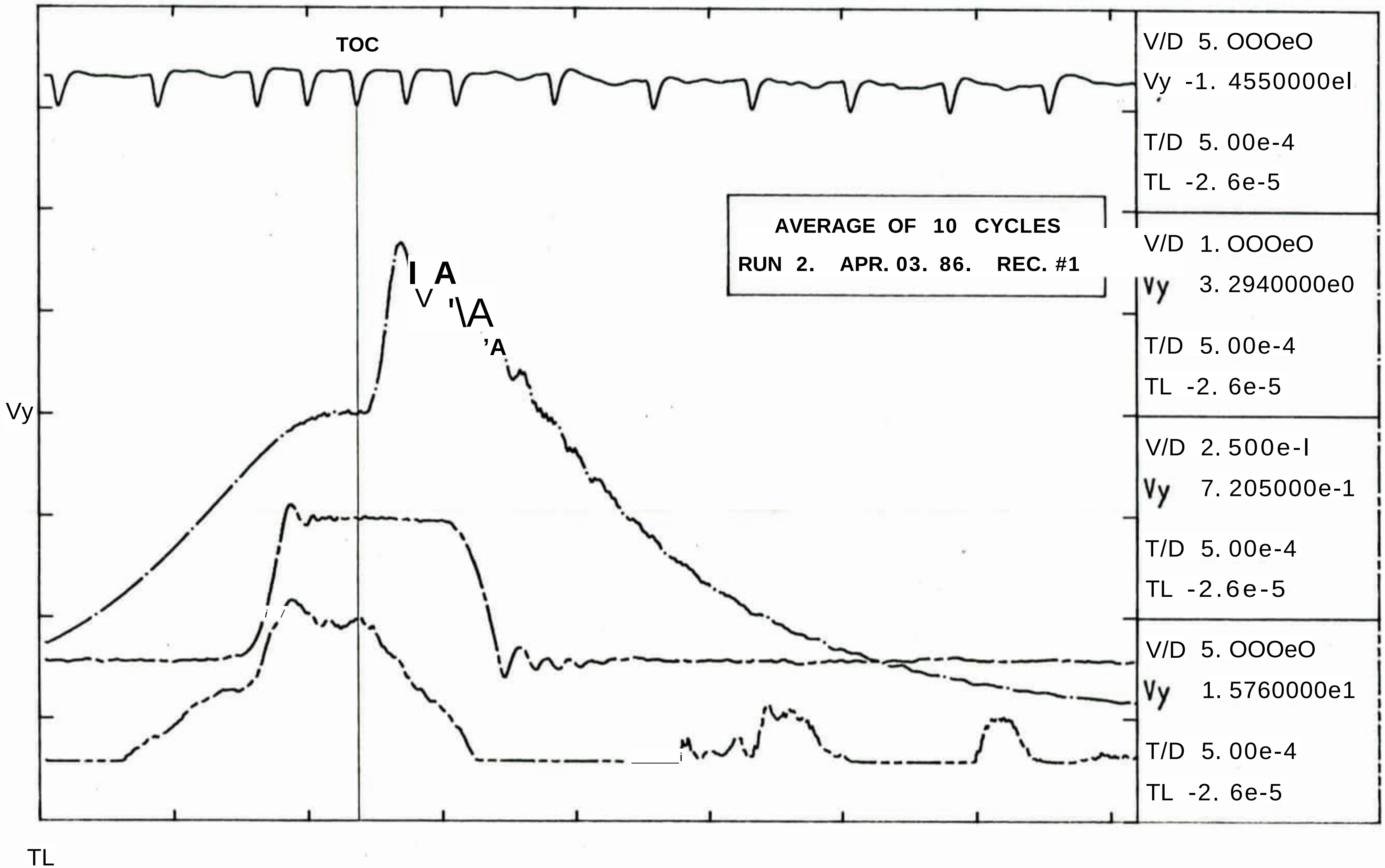

FIG. 43   75 REV/S SN=4 -26 DEG CR

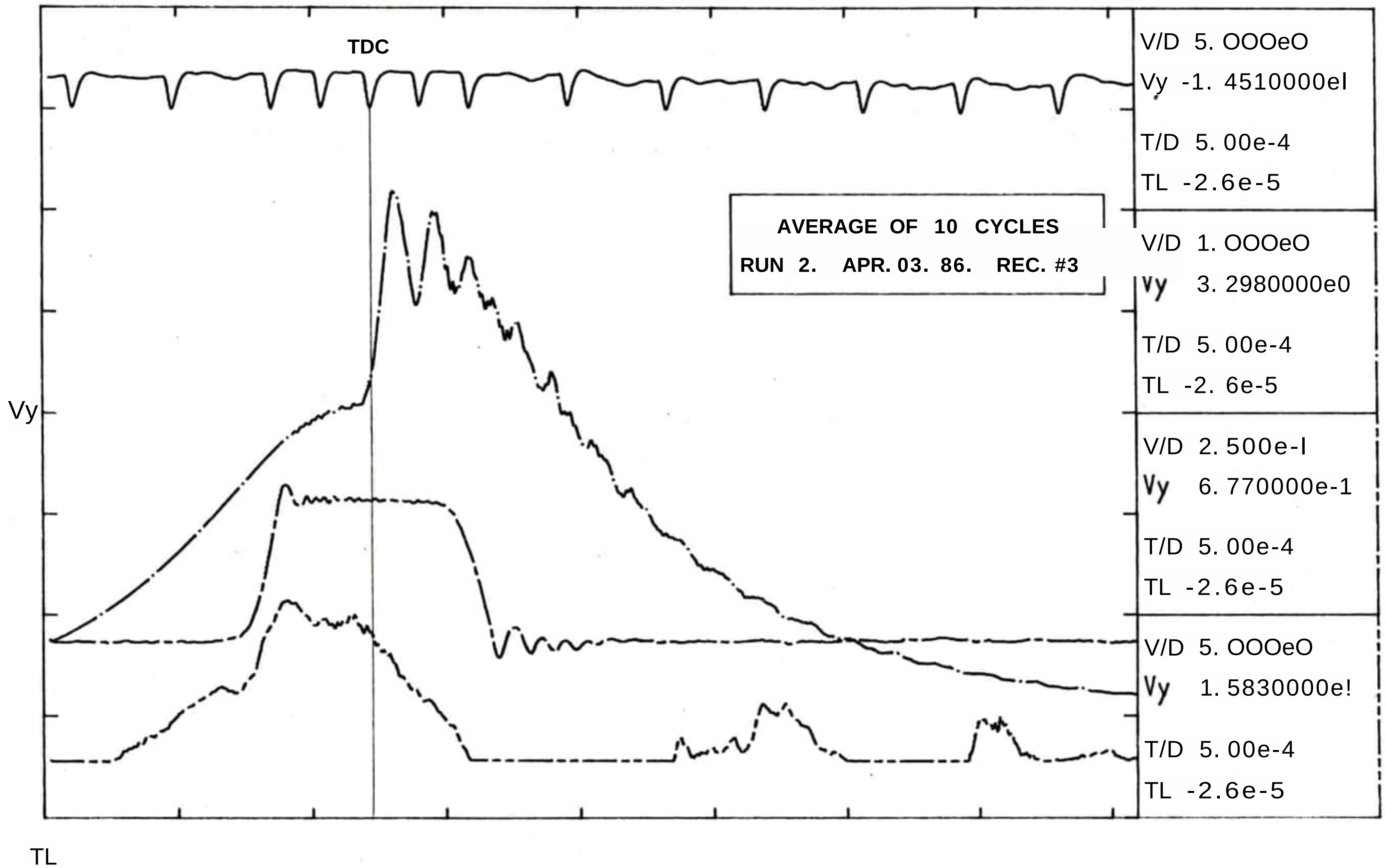

FIG. 44 75 REV/S SN=4 -28 DEG CR

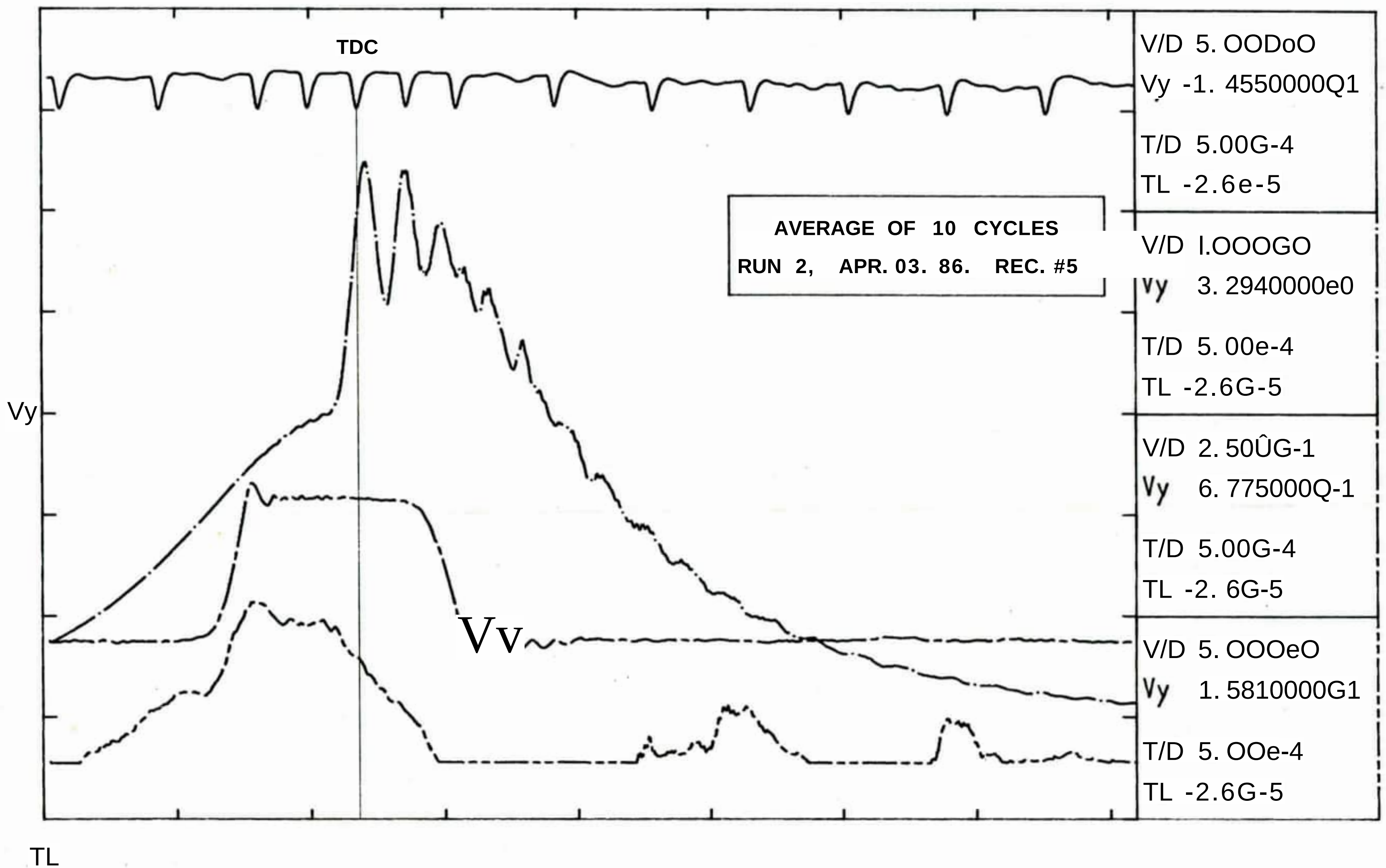

FIG. 45 75 REV/S SN=4 -30 DEG CR

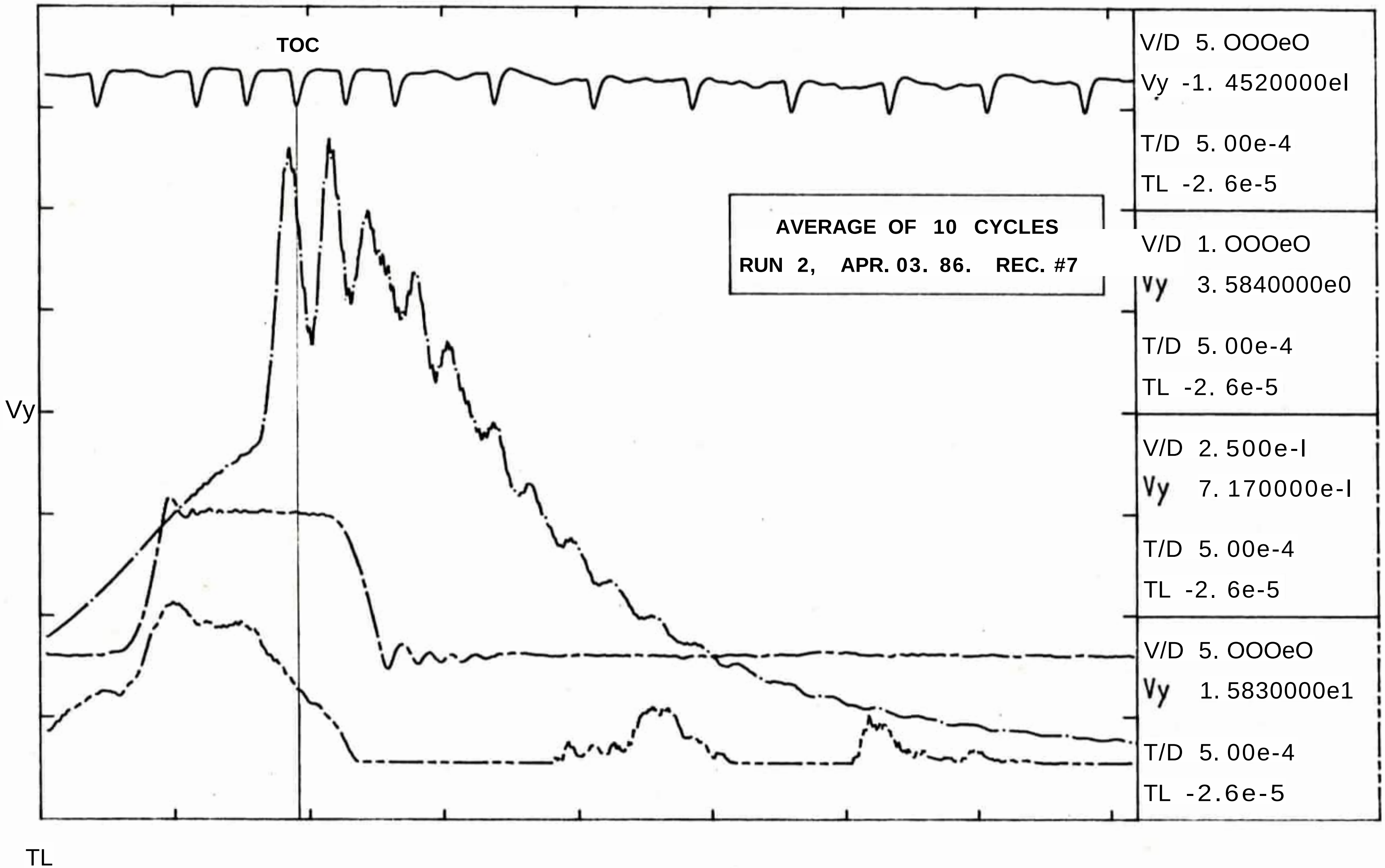

FIG. 46 75 REV/S SN=4 -32 DEG CR

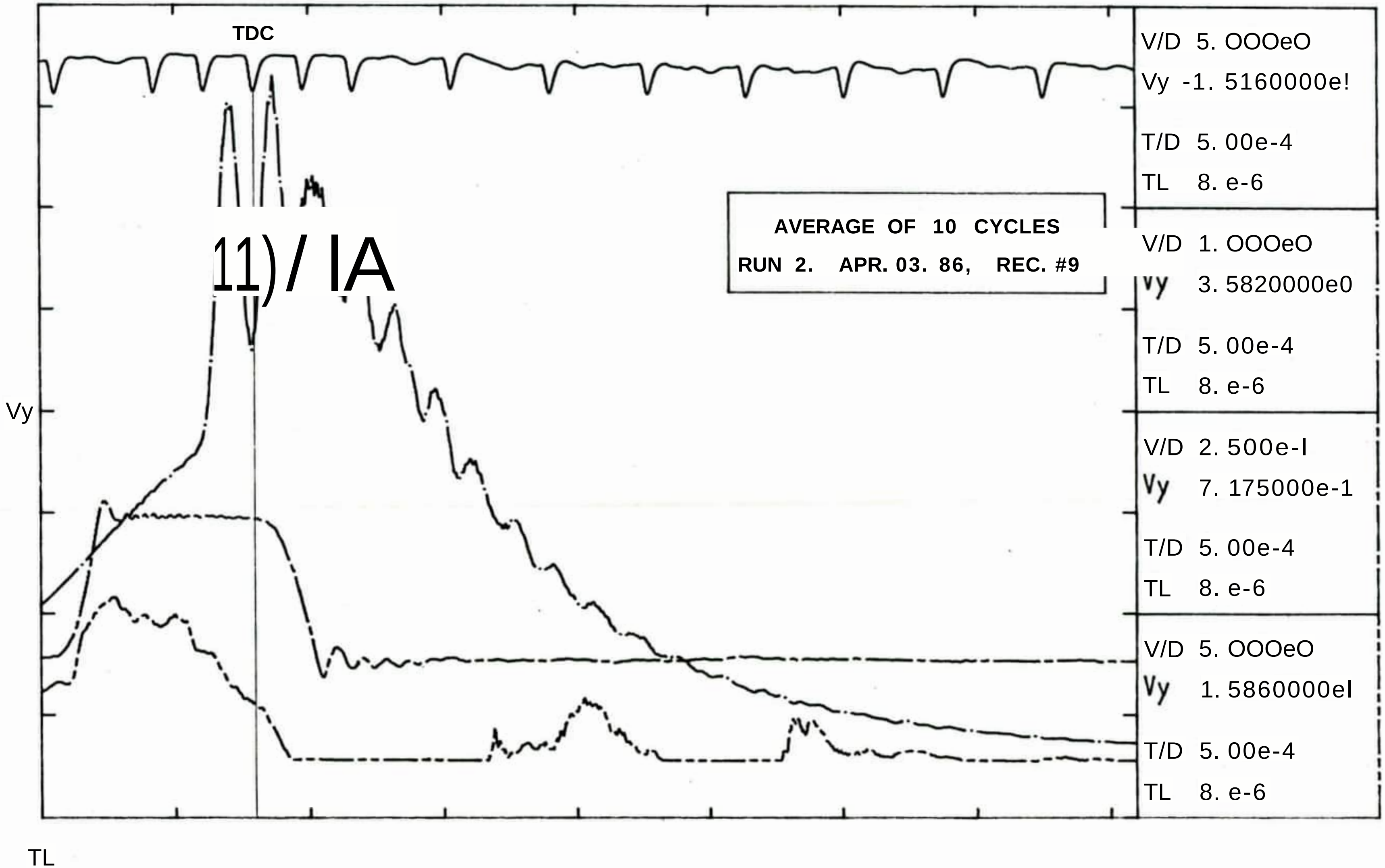

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FIG. 47 75 REV/S SN=4 -28 DEG CR

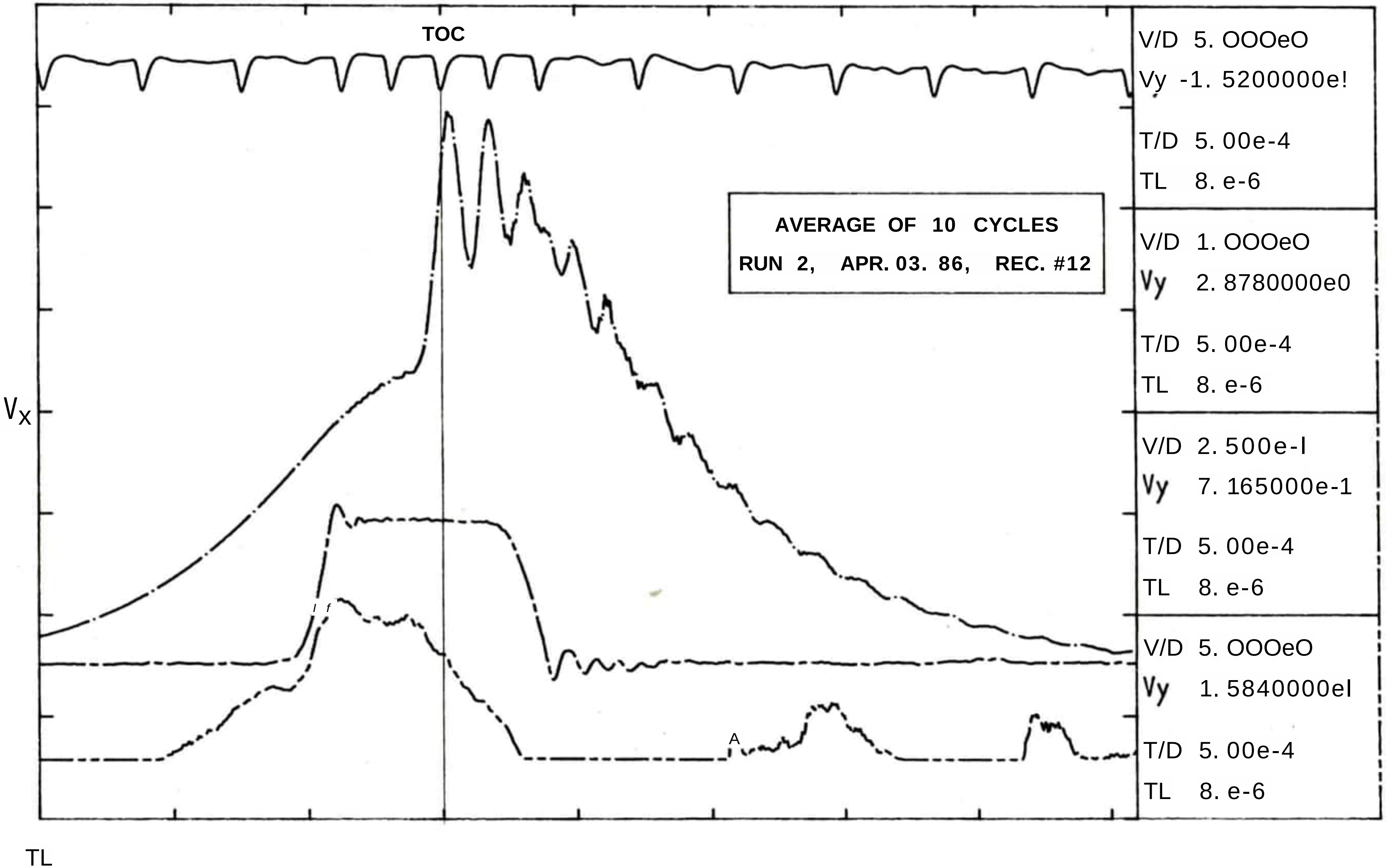

FIG.48 40 REV/S 7 NM -21 DEG CR

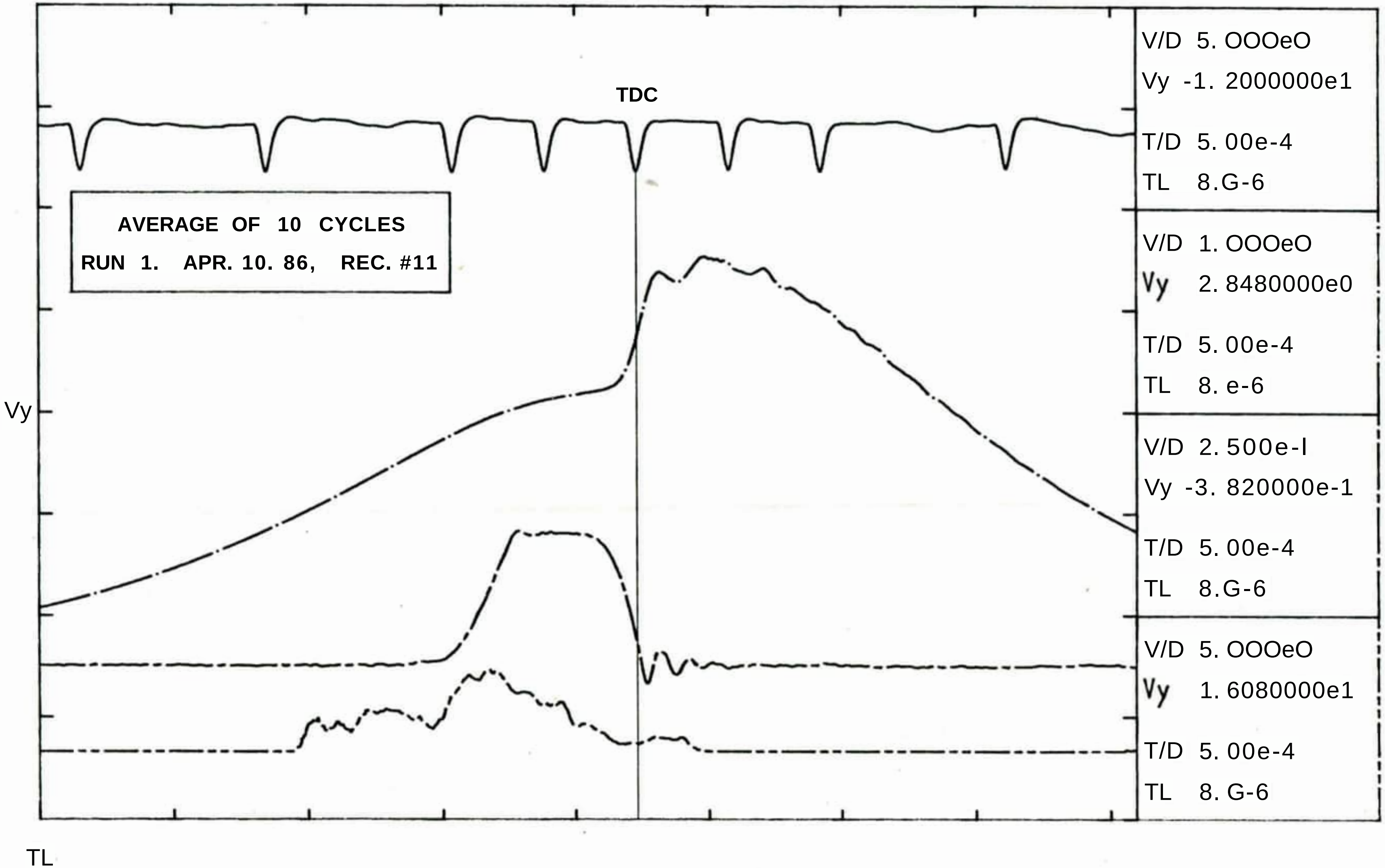

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FIG.49 40 REV/S 14NM -19 DEG CR

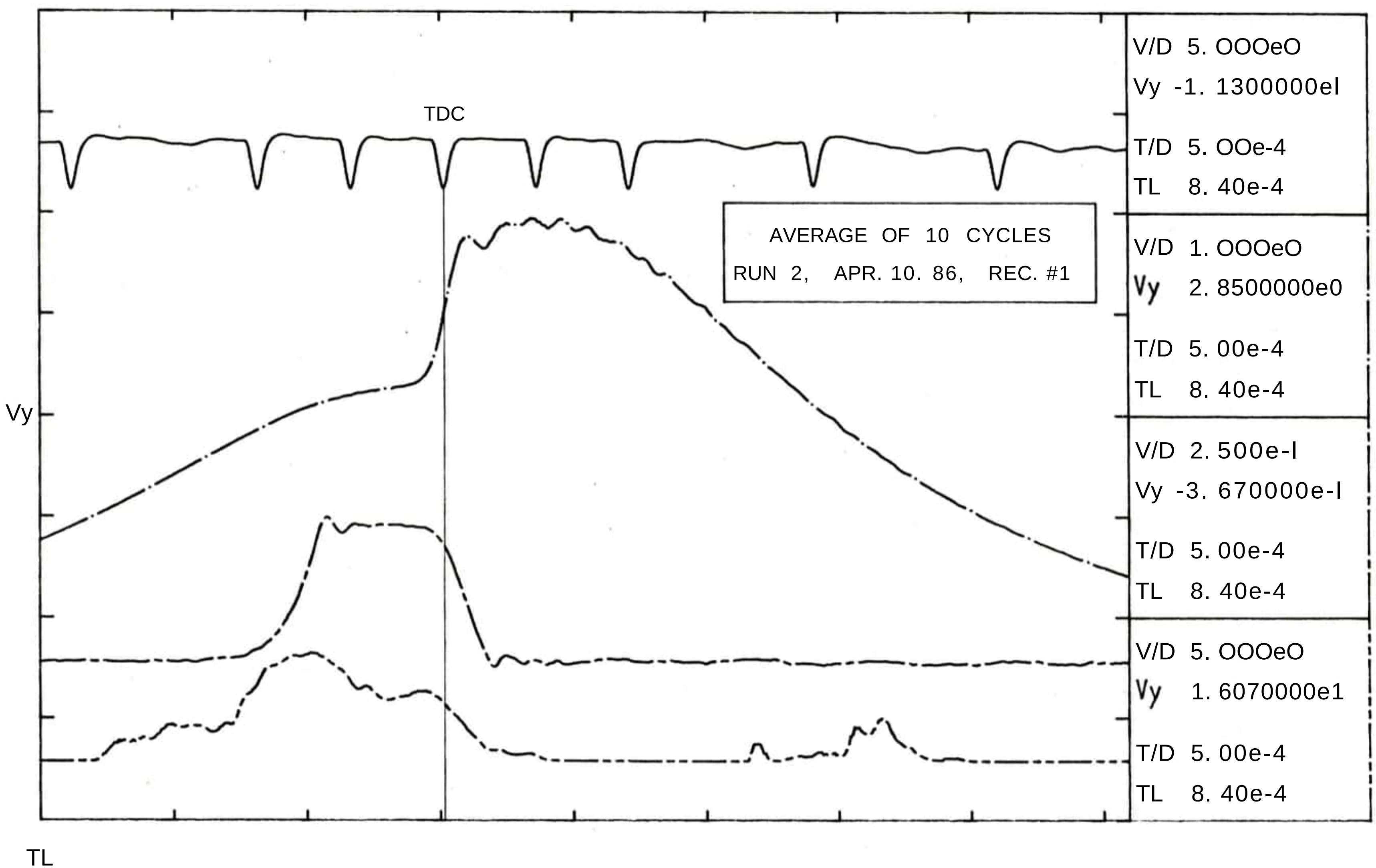


FIG. 50 65 REV/S 7 NM -28 DEG CR

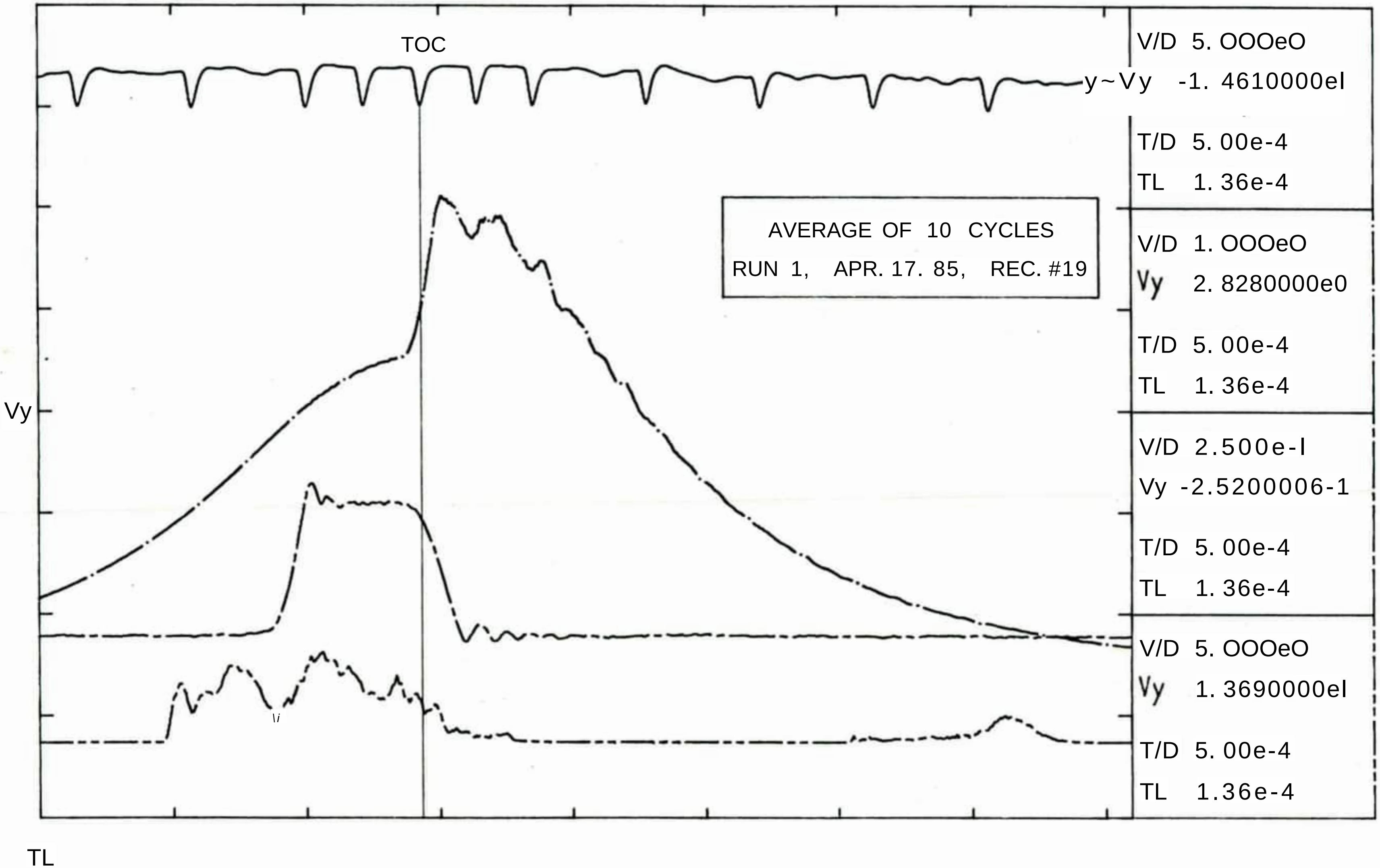


FIG. 51 65 REV/S 14NM -24 DEG CR

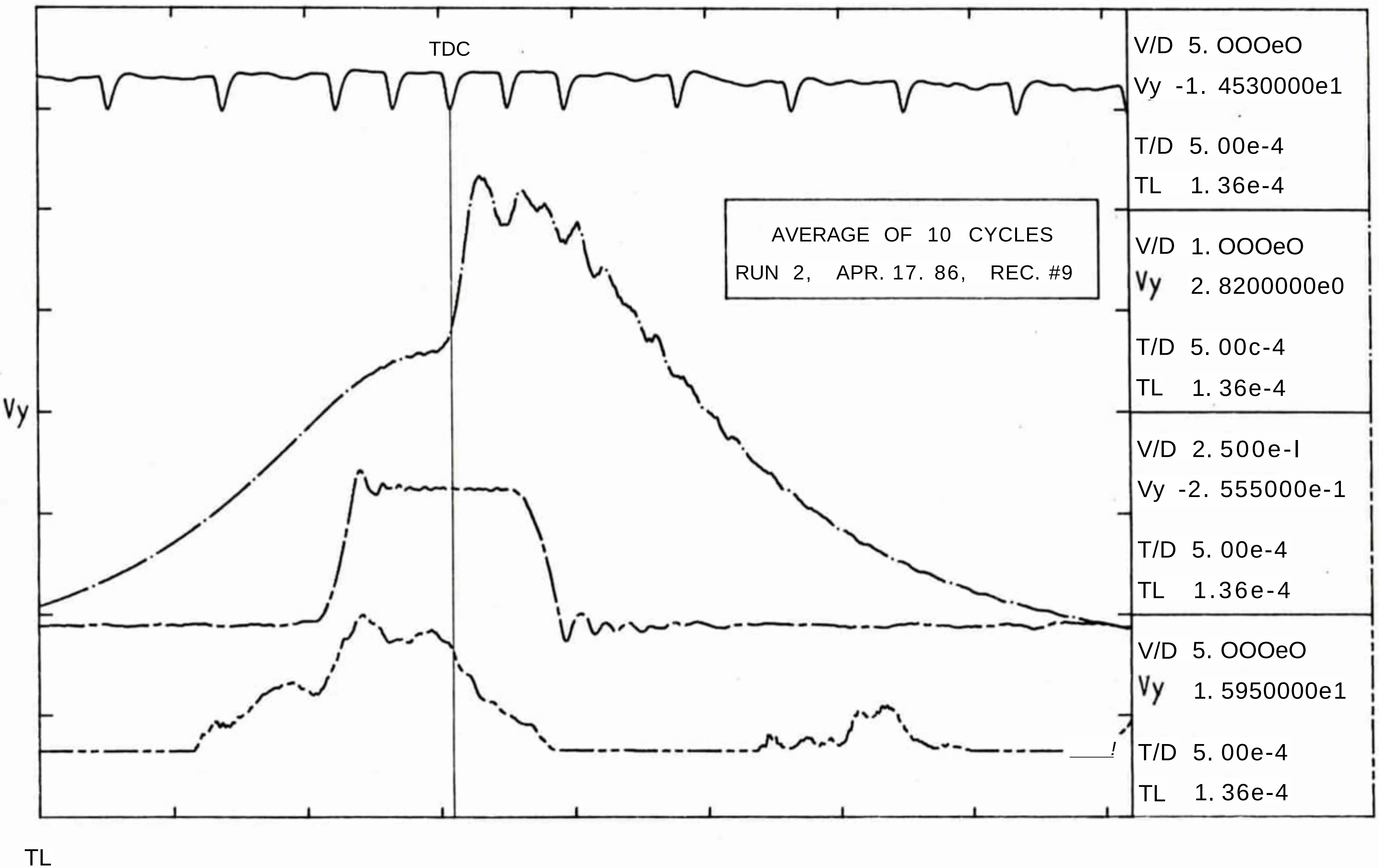
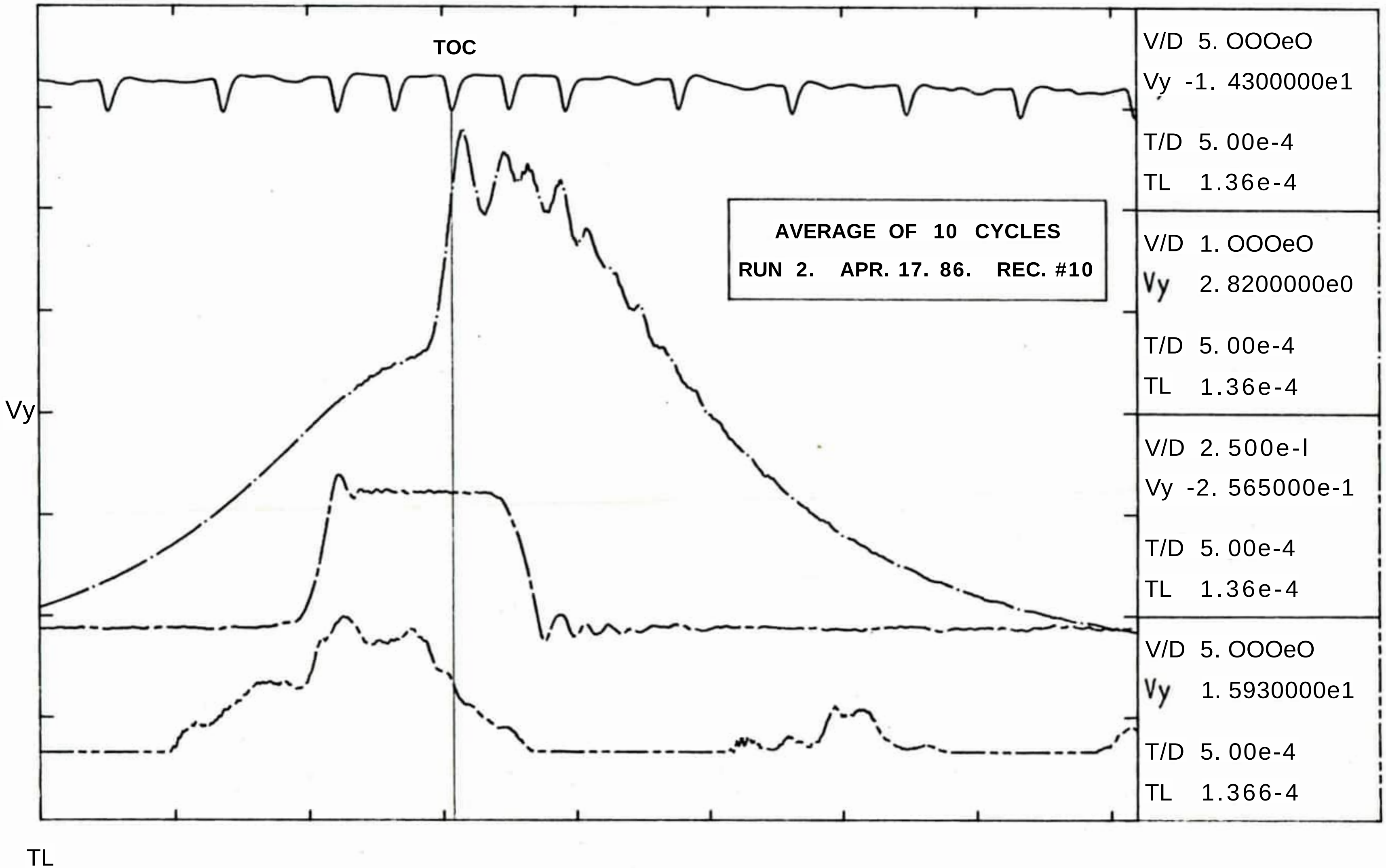


FIG. 52 65 REV/S 14NM -26 DEG CR



FIG» 53 75 REV/S 7 NM -28 DEG CR

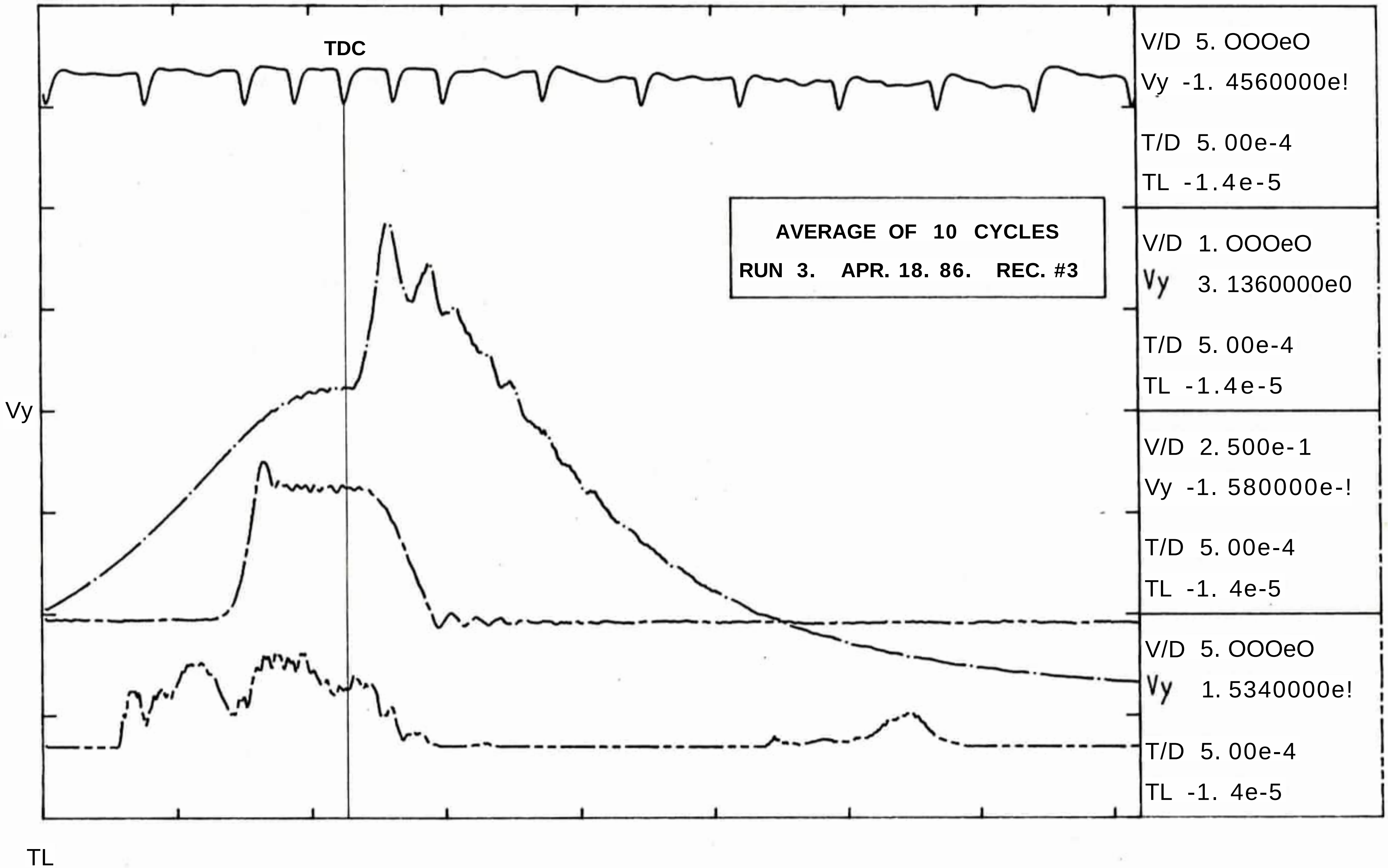


FIG.54 75 REV/S 7 NM -24 DEG CR

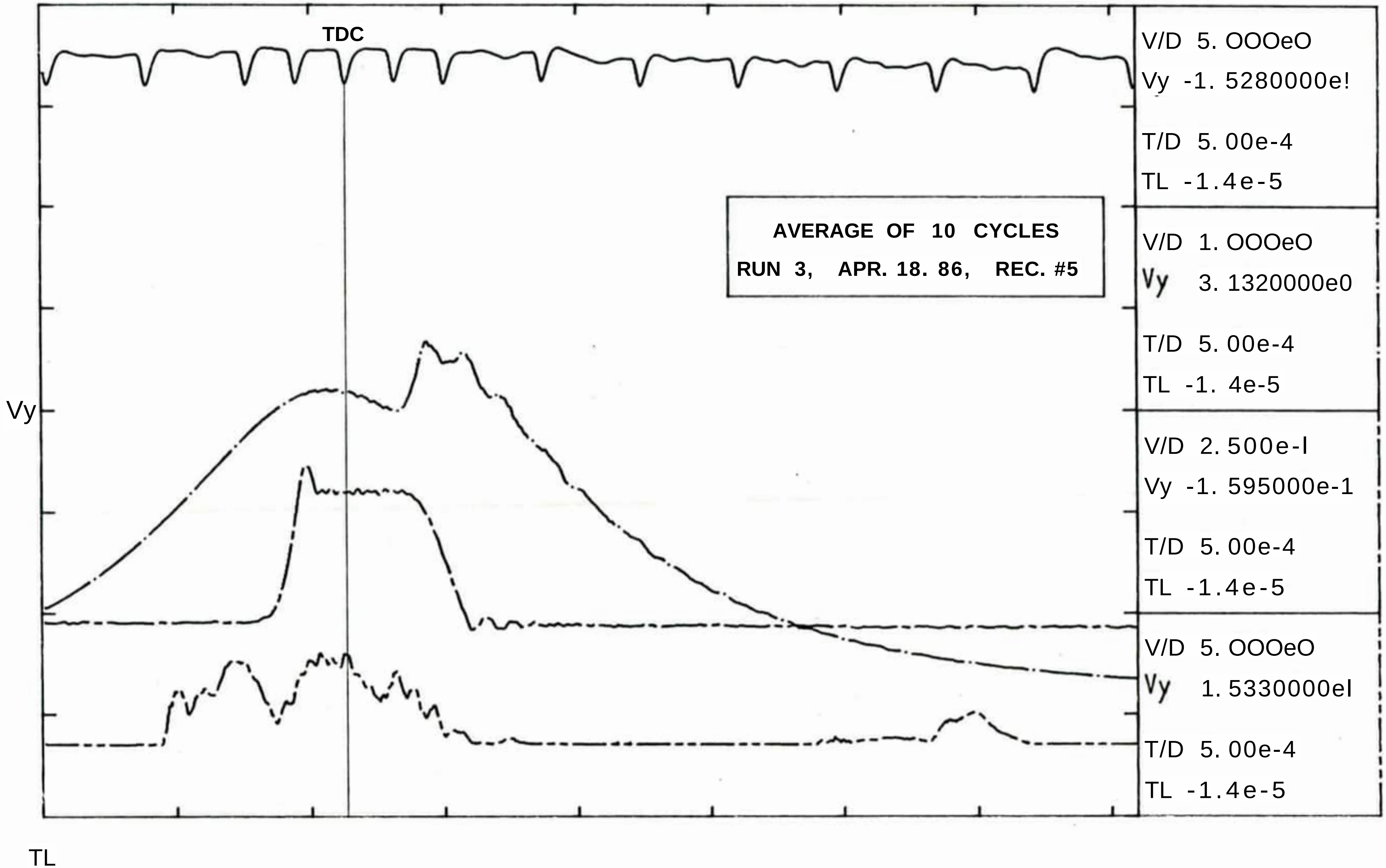


FIG. 55 75 REV/S 7 NM -26 DEG CR

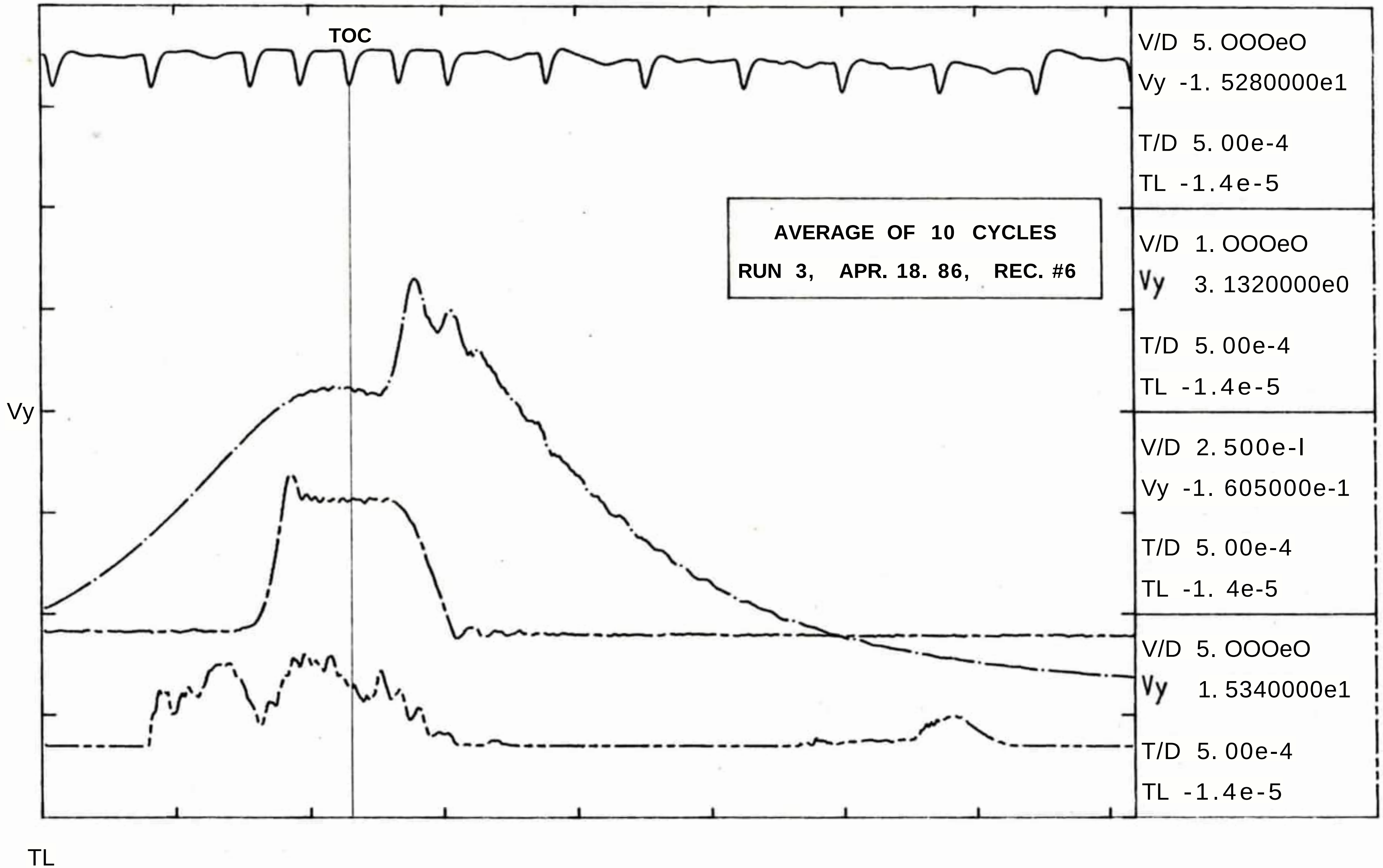


FIG. 56 75 REV/S 7 NM -28 DEG CR

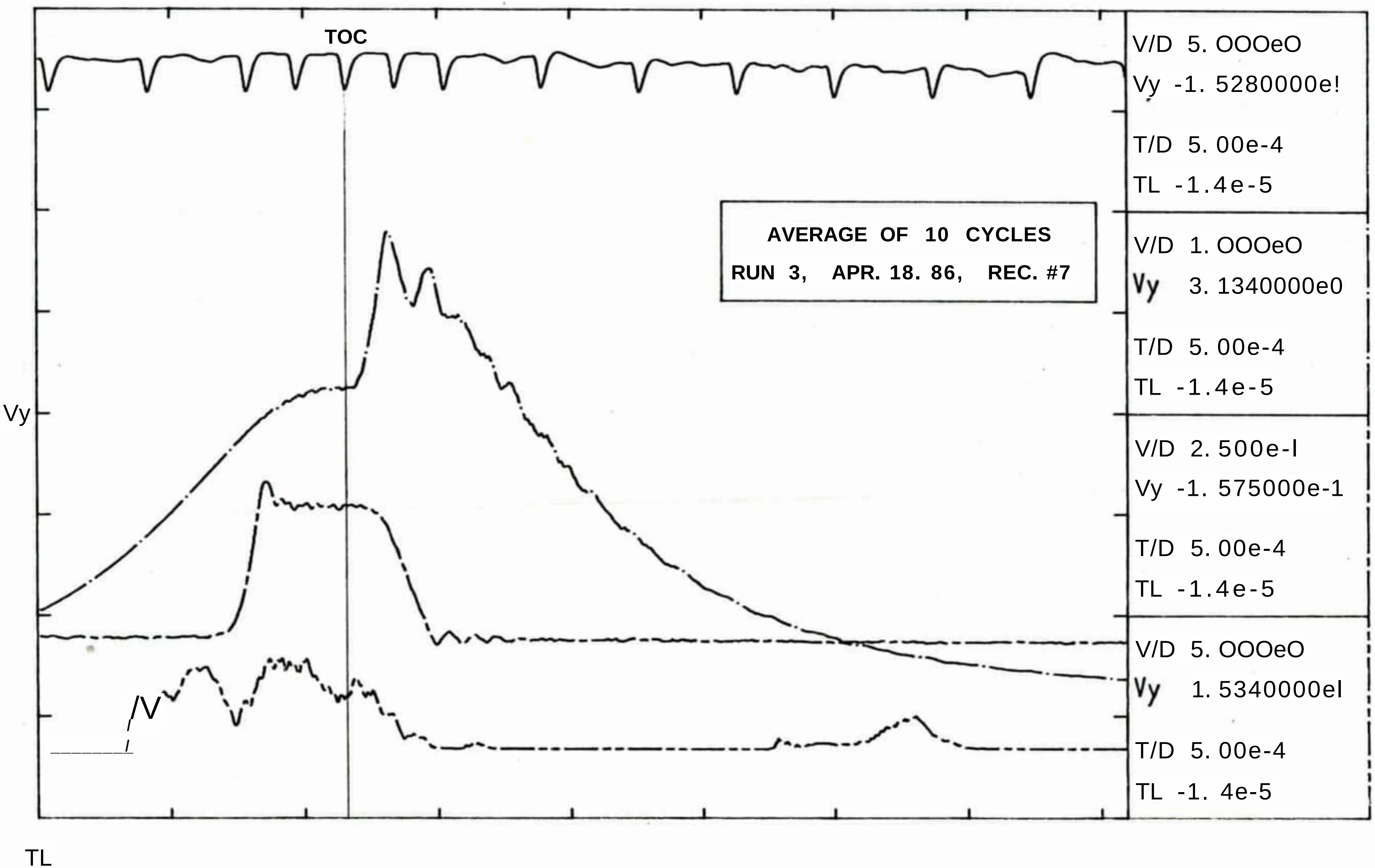


FIG. 57   75 REV/S 7 NM -30 DEG CR

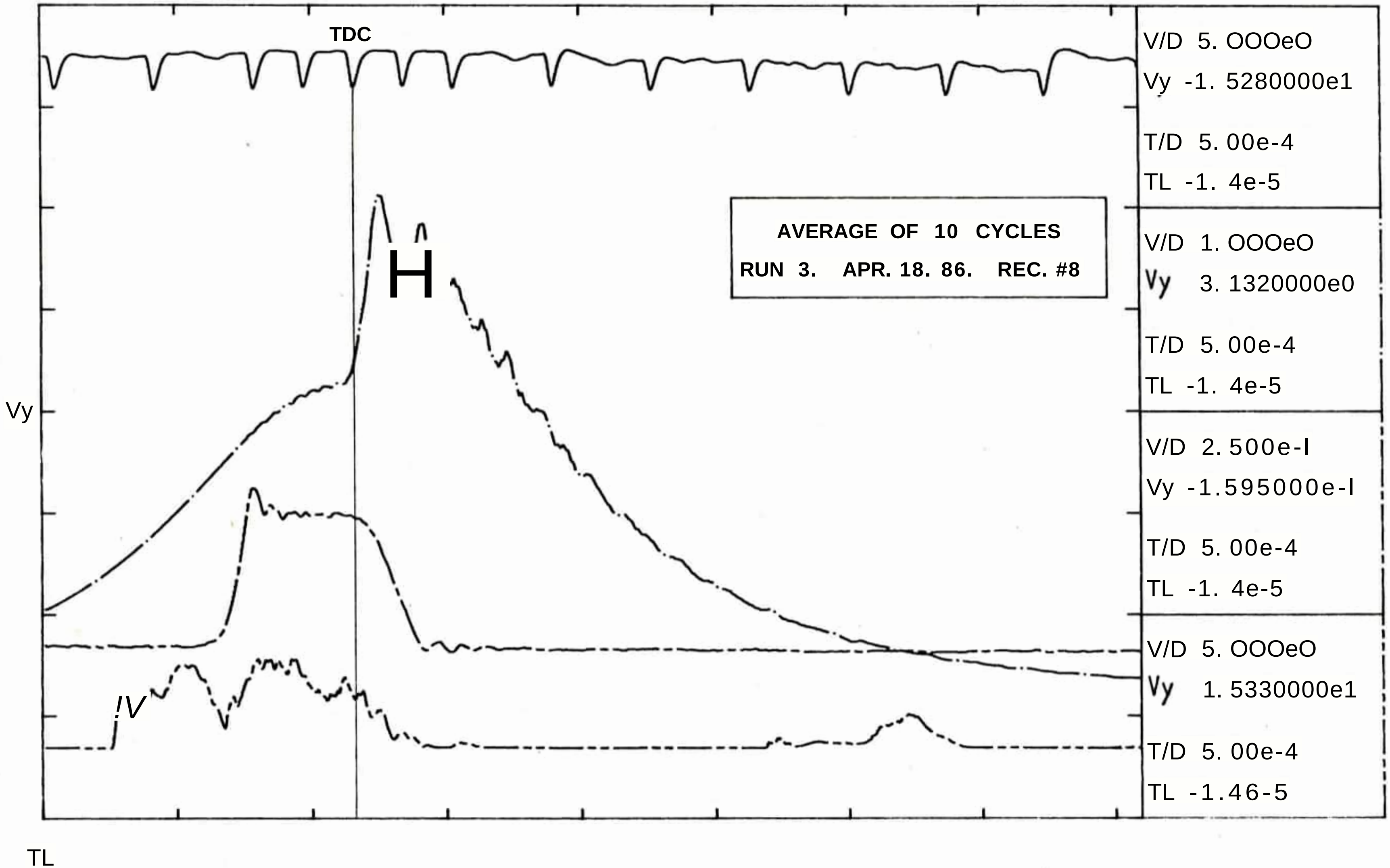


FIG. 58 75 REV/S 7 NM -32 DEG CR

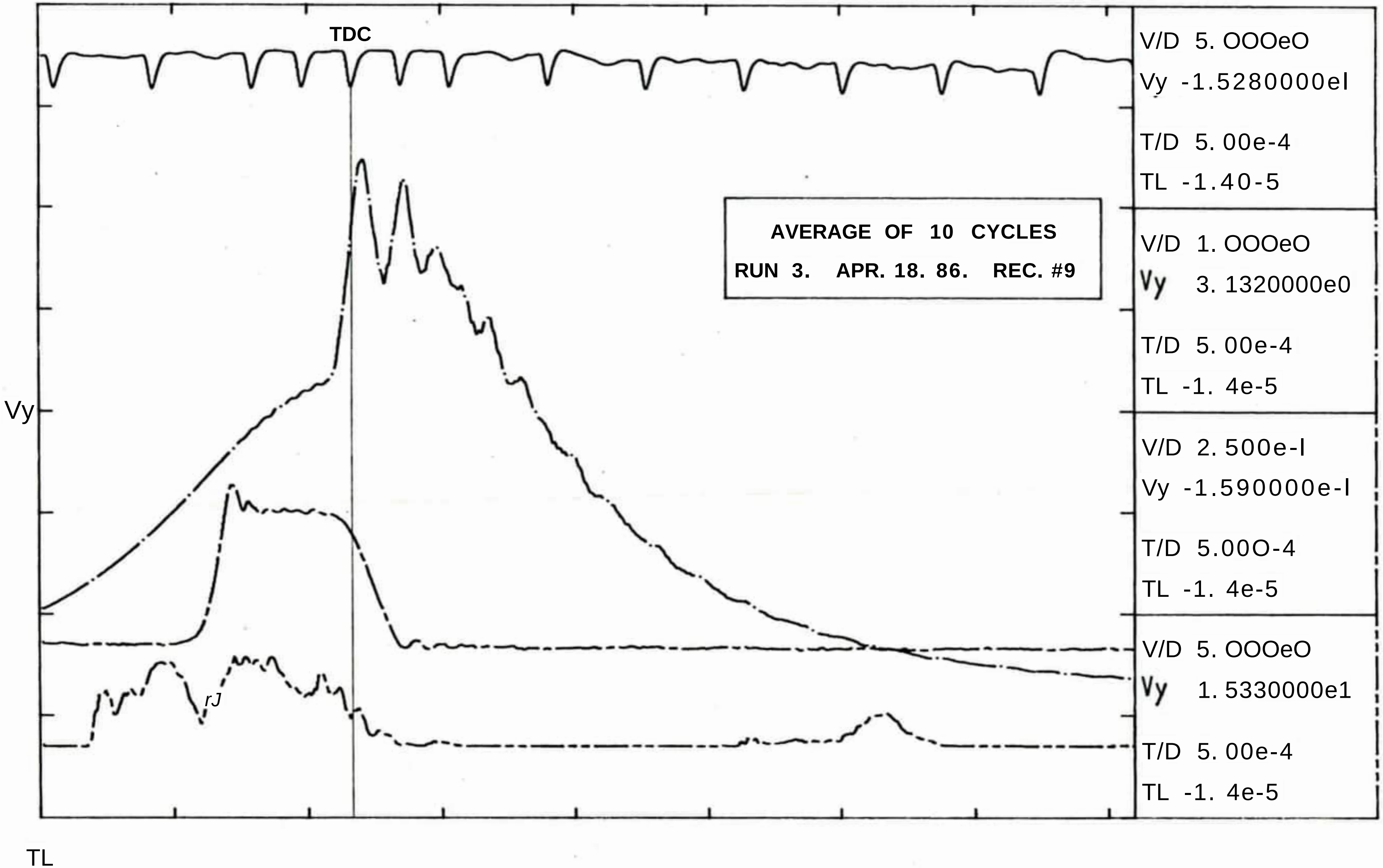
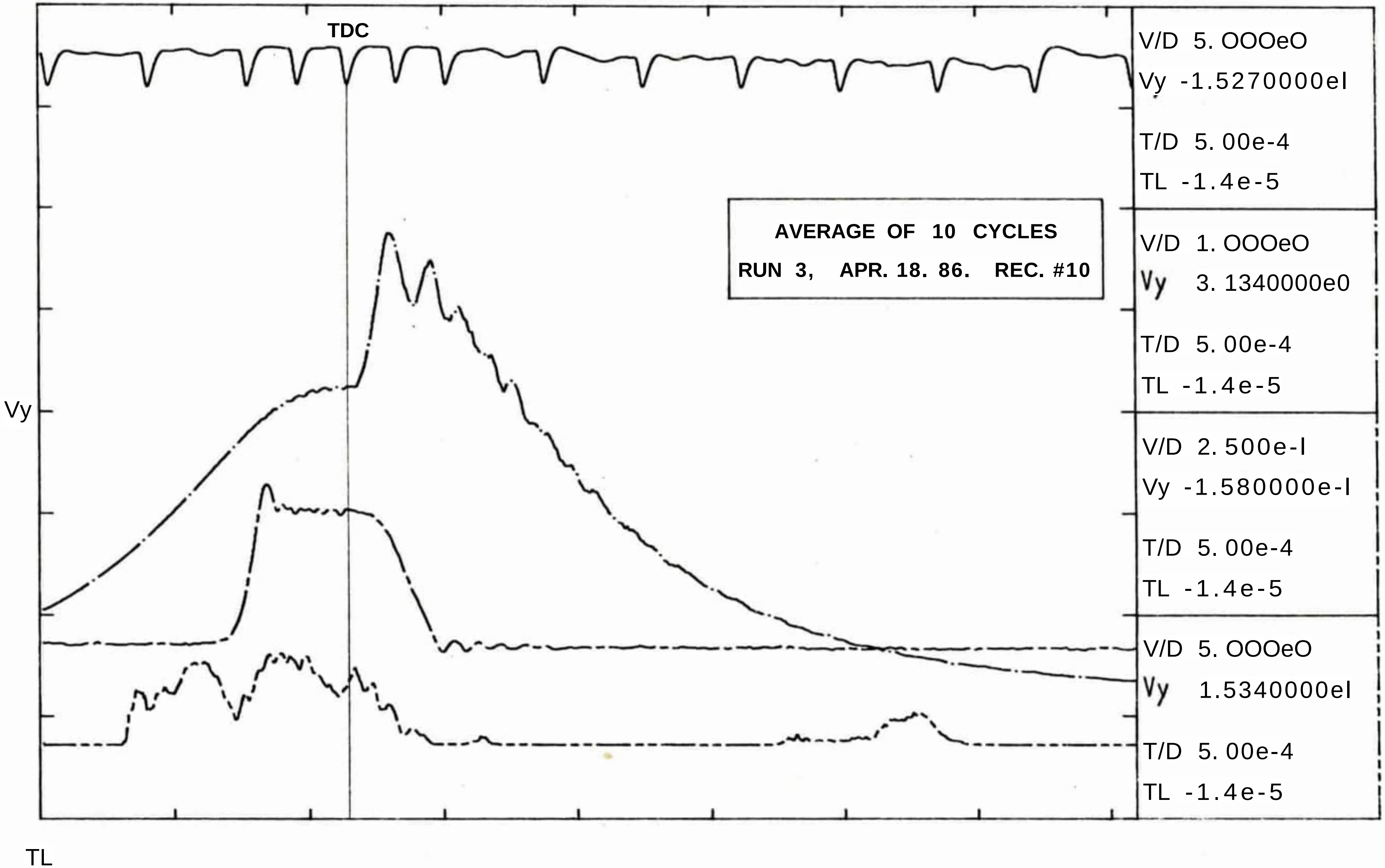


FIG. 59 75 REV/S 7 NM -28 DEG CR



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5

TITLE, SUBTITLE/TITRE, SOUS-TITRE

6 Optimization of Direct Injection Ricardo Hydra Test Engine on #2 Diesel Fuel

AUTHOR(S)/AUTEUR(S)

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SERIES/SÉRIE

8

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AUTEUR D'ENTREPRISE/AGENCE D'EXÉCUTION

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NOTES

17

DESCRIPTORS (KEY WORDS)/MOTS-CLÉS

18 Single cylinder research diesel engine, fuel tests, test cell

SUMMARY/SOMMAIRE
Injection timing optimization of the direct injection Ricardo Hydra single cylinder research engine on #2 diesel fuel is described.
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