ENERGILABORATORIET ENERGY RESEARCH LABORATORY

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DETTE PROJEKT VAR FINANCIERET GENNEM
ENERGIMINISTERIETS FORSKNINGSPROGRAM
EFP 87

NIKKEL - JERN BATTERI

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Marts 1989

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FORORD

Nærværende projekt er udført på basis af et projekttilskud fra Energiministeriet under betegnelsen "Nikkel-jern batteri" EFP 87, EM journal nr. 1443/87-3.

Projektet er en fortsættelse af et tidligere projekt med samme navn under EFP 86, EM journal nr. 1443/86-4.

Projektet er et batteriprøvningsprogram, som har til formål at indhøste viden om den nyeste batteriteknologi inden for området energilagringssystemer til transportformål.

Udførelsen fandt sted på ENERGILABORATORIET (ERL A/S) under ledelse af afdelingsleder Henrik Amdi Petersen, Batteritestlaboratoriet.

Projektek er fuldført ifølge projektplanen.

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INDHOLDSFORTEGNELSE

1. INDLEDNING

Dette projekt tager sit udgangspunkt i en ny generation af nikkel-jern batteriet, som blev introduceret i midten af dette årti.

Den nye type skulle udmærke sig ved at have langt bedre energi- og effekttæthed end de nikkel-jern batterier, som er blevet anvendt især i USSR og USA i henved 100 år. Endvidere så man muligheden for at benytte det forbedrede batteri som en afløser for blybatteriet i forbindelse med elbiler og andre lette elkøretøjer.
Det nye nikkel-jern batteri har dog aldrig været betragtet som det "avancerede batteri", men nærmere som en overgangsløsning fra bly-batteriet og frem til det tidspunkt, hvor det lykkes at producere det "ideelle" elbilbatteri.

Projektets formål var at foretage en laboratorieprøvning af denne nye generation af nikkel-jern batteriet ved hjælp af prøvningsmetoder, som allerede er anerkendt i forbindelse med blybatterier, for at klarlægge de påståede forbedrede egenskaber m.h.t. ydeevne og levetid, samt at tilvejebringe et mere komplet billede af batteriets funktion i forbindelse med den tiltænkte drift i elkøretøjer.

Med udgangspunkt i nævnte problemstilling indeholder denne rapport resultatet af de prøvninger og erfaringer, som projektets gennemførelse på ENERGILABORATORIET har ført frem til.

Som appendix til rapporten er vedlagt informationsblad for Batteritestlaboratoriet samt det tilgængelige materiale vedrørende de omhandlede nikkel-jern batterier.

2. MALEEMNE, MALEPROCEDURE OG MALERESULTATER

2.1 MALEEMNE

Følgende batterimoduler blev anvendt til prøvningen :

SAFT 6 v 230 Ah monobloc

2.2 MALEPROCEDURE

Der blev opbygget to prøvestande, hver med plads til to moduler, således, at hver af de to parralelprøvninger blev udført med med en batterispænding på 12 v.

Teststandene blev opbygget således, at følgende parametre automatisk blev kontrolleret og overvåget:

-automatisk af- og opladning med kontinuerlig udlæsning af data (i fig. 1 (side 8) er vist en typisk afladekurve).

-automatisk vandpåfyldning og registrering af vandforbrug

-automatisk styring af strøm og temperatur under af- og opladning

2.3 MALERESULTATER

Målingerne blev foretaget med batterierne anbragt i vandbad ved + 20° C.

Under projektforlængelsen (EFP 87 projektet) blev der foretaget en række supplerende målinger på et NI-FE batteri, som efter retnings- linier fra fabrikanten (SAFT, Frankrig) blev bygget på ENERGILABORATORIET af komponenter fra produktionen af den første prototypeserie.

De indledende kapacitetsprøver viste resultater, som nøje svarede til dem, som blev opnået med de batterier, som var samlet på fabriken i Frankrig. Derefter fortsattes prøvningen med det "nye" batteri.

Efter afslutningen af denne sidste prøvningsserie kan følgende ydelsesmæssige egenskaber for NI-FE batteriet som type opstilles :

Type	:	SAFT NI-FE monobloc 6 V 230 Ah
Dimensioner	:	L: 245 mm B: 190 mm H: 255 mm (280 mm)
Volumen	:	11.87 liter (excl. propper og terminaler)
Vægt	:	27.2 kg (incl. elektrolyt)

De målte værdier var følgende:

Kapacitet :	228.2 Ah
Energiindhold :	1460.48 Wh
Middelspænding under afladning :	6.4 volt
Energitæthed (vægt) :	53.7 Wh/kg
Energitæthed (volumen) :	123.0 Wh/l
Effekkttæthed (15 sek.) :	168.2 W/kg
Energimæssig virkningsgrad :	ca. 50 %
Nødvendig ladefaktor (Ah) :	1.3 - 1.7

En levetidsprøvning af de 2 gange 2 moduler blev gennemført under henholdsvis EFP 86 projektet og EFP 87 projektet.

De to levetidskurver er vist i figur 2. og 3. (side 9 og 10).

Den anvendte afladestrøm var 5-timers strømmen, og opladningen af batterierne blev udført efter fabrikantens anvisninger.
Den anvendte ladefaktor var 1.5 (forholdet mellem indladet og afladet kapacitet). Denne blev senere ændret til ca. 1.3, idet der viste sig problemer med funktionen af de monterede vandpåfyldningspropper.

3. KONKLUSION

Den forventede levetid på ca. 2000 afladninger blev ikke opnået.
Årsagen dertil lå alene i den dårlige funktion af de omtalte propper, hvorfor det opnåede resultat (ca. 200 afladninger) ikke kan anses for repræsentativt for denne batteritype.

NI-FE batteriets grundlæggende egenskaber kan summeres som følger:

ENERGITÆTHEDEN er væsentligt bedre end i blybatteriet, idet den anvendelige energitæthed i praktisk drift i en elbil ligger tæt på 45 Wh/kg mod blybatteriets ca. 25 Wh/kg. Dette gælder over hele temperaturområdet (-25° C - +40° C), dog er praktisk anvendelse af NI-FE batteriet ved temperaturer under 0° C vanskelig, idet et nødvendigt automatisk vandpåfyldningssystem da ikke fungerer.

EFFEKTTÆTHEDEN er ligeledes bedre end i blybatteriet: ca. 170W/kg mod ca. 100 - 115 W/kg for sidstnævnte.

DEN ENERGIMÆSSIGE VIRKNINGSGRAD på ca. 50 % for NI-FE batteriet er forholdsvis ringe, sammenlignet med de fleste andre elektrokemiske systemer. Dette skyldes en stor forskel på cellespændingen under op- og afladningen. Hvor blybatteriet typisk har et forhold mellem disse to spændinger på 1 - 1.15 er den tilsvarende difference for NI-FE batteriet 1 - 1.30. Dette forhold betyder, at NI-FE batteriet ikke egner sig til brug i stationære anlæg, hvor det står til ladning med konstant spænding. Et spændingsfald på henved 25 % af normspændingen i en nødforsyningssituation vil ikke kunne accepteres.

DE TERMISKE FORHOLD i NI-FE batteriet er det væsentligste problem for en praktisk anvendelse af systemet i f.eks. et el-køretøj. Den indre modstand er ganske stor - typisk 5-6 gange større end for et blybatteri af tilsvarende konstruktion. Dette medfører en anseelig opvarmning i både oplade- og afladesituationen. Da temperaturstigningen øges med såvel afladestrømmens størrelse som med afladningsdybden, nåes hurtigt et punkt, hvor batteritemperaturen er så høj, at yderligere afladning vil have stærk negativ indflydelse på batteriets levetid.

Som eksempel kan nævnes, at kontinuerlig op- og afladedrift med 5 timers strømmen (46A) i løbet af ca. et døgn medfører en elektrolyttemperatur på 55-60° C til trods for at, batteriet var anbragt nedsænket i et vandbad med kontrolleret temperatur på 25° C.

Det er således batteriets termiske egenskaber, som i praksis er begrændsende for afladningsdybden, især ved høje belastningsstrømme, som batteriet var tiltænkt at afgive under anvendelse i f.eks. en elbil.

4. EFTERSKRIFT

Projektforlængelsen under EFP-87 har muliggjort et tættere samarbejde mellem ENERGILABORATORIER og udviklingsafdelingerne hos de fabrikanter, som har været involveret i konstruktionen af den nye generation af nikkel-jern batterier.

Det må dog beklageligvis ved dette projekts afslutning konstateres, at samtlige os bekendte forsøg på at frembringe et batterisystem med tilstrækkeligt positive egenskaber er opgivet. De to mest aktive firmaer er SAFT i Frankrig og SAB-NIFE/EAGLE PITCHER i Sverige/USA. Begge firmaer har opgivet videre udvikling af den negative jernelektrode.

Disse firmaer har dog indhøstet så megen viden omkring elektrodereaktioner i alkaliske elektrolytter, at det udførte udviklingsarbejde på ingen måde har været spildt. Resultatet blev imidlertid ikke det forholdsvis miljøvenlige nikkel jern batteri, men istedet et meget bedre nikkel-cadmiun batteri, hvor specielt de forbedrede produktionsmetoder har nydt godt af de indhøstede erfaringer.

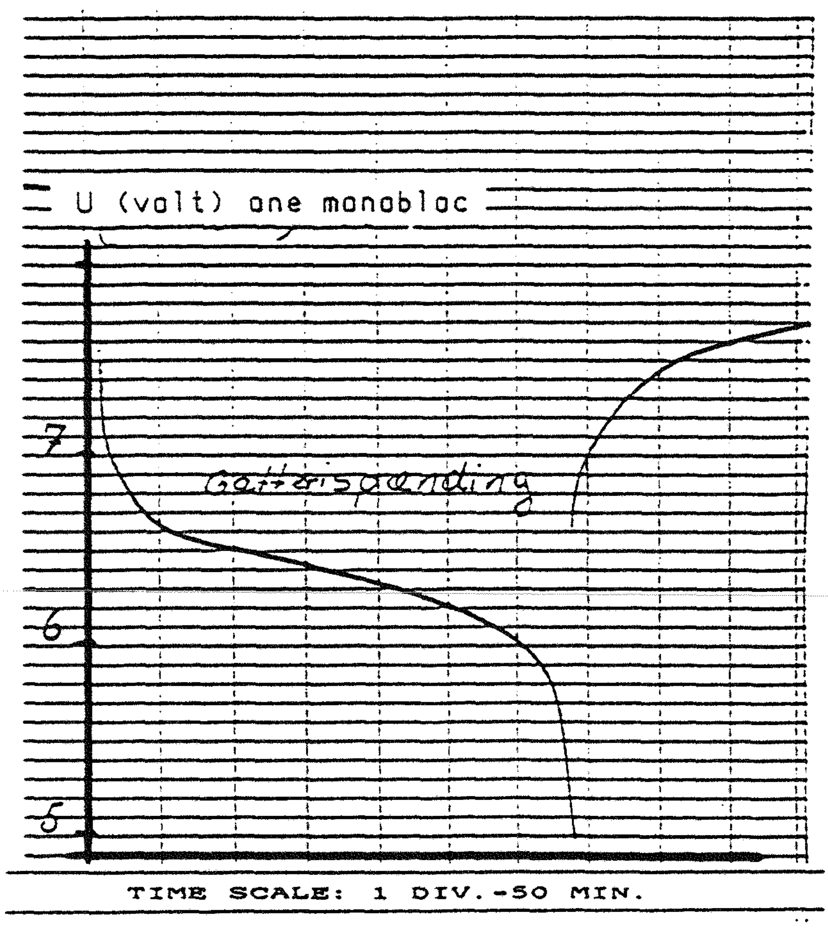
Som væsentligste årsager til at afslutte udviklingsarbejdet med NI-FE batteriet angiver fabrikanterne følgende:

1. Uanvendeligt i automotive systemer (el-biler) på grund af et meget stort vandforbrug, hvilket umuliggør normal drift ved temperaturer under frysepunktet (0°C).

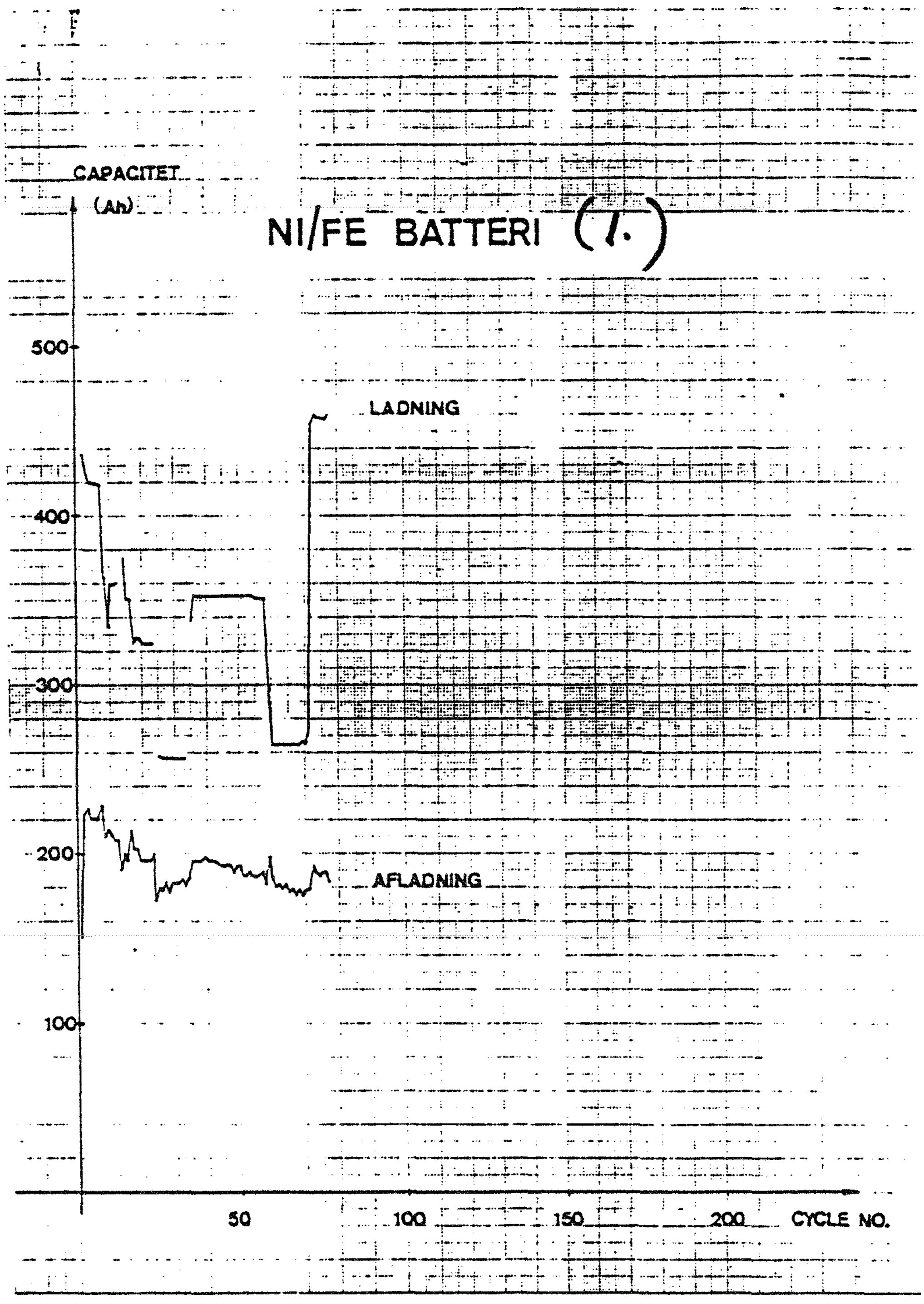
2. Den forventede levetid på ca. 2000 afladninger er kun opnået i få tilfælde, og da under termisk kontrollerede forhold i laboratorium.

3. Det har ikke været muligt at opnå et sådant design, at termisk management af batteriet i den normale driftsituation har kunnet undgås.

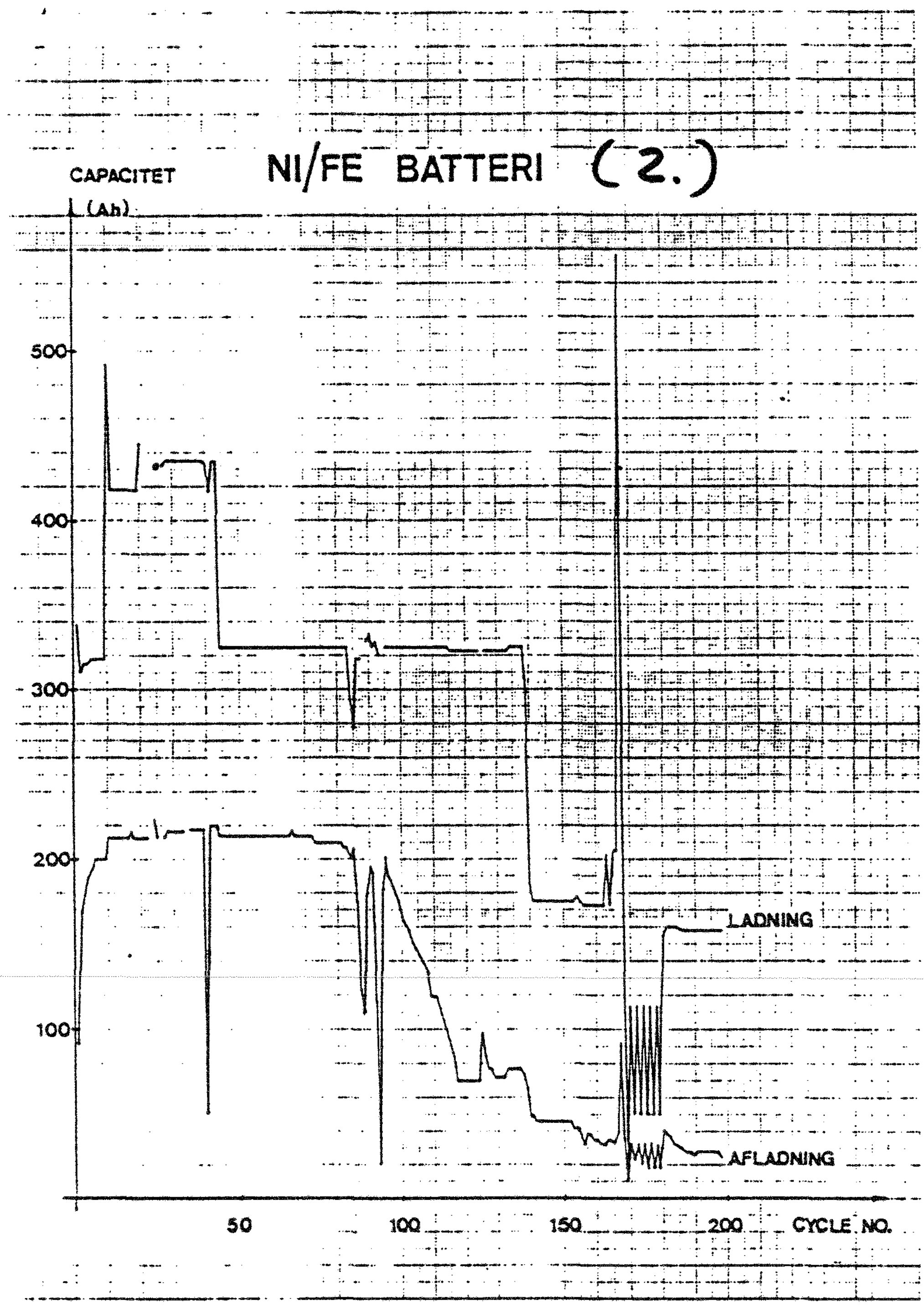
4. Endeligt skal beslutningerne om standsning af udviklingsprojekterne ses i lyset af en gunstig udvikling af prisen på blybatterier til samme anvendelsesområder. Det ville med andre ord ikke være muligt for nikkel-jern batteriet, selv efter løsning af samtlige ovenfor nævnte problemer, at konkurrere med blybatteriet i den kvalitet, som det i dag tilbydes kunderne.



Figur 1. Typisk afladningskurve for et nikkel-jern batteri (SAFT) med 5-timers strømmen (46 A)



Figur 2. Levetidskurve for det prøvede nikkel-jern batteri (EFP 86)



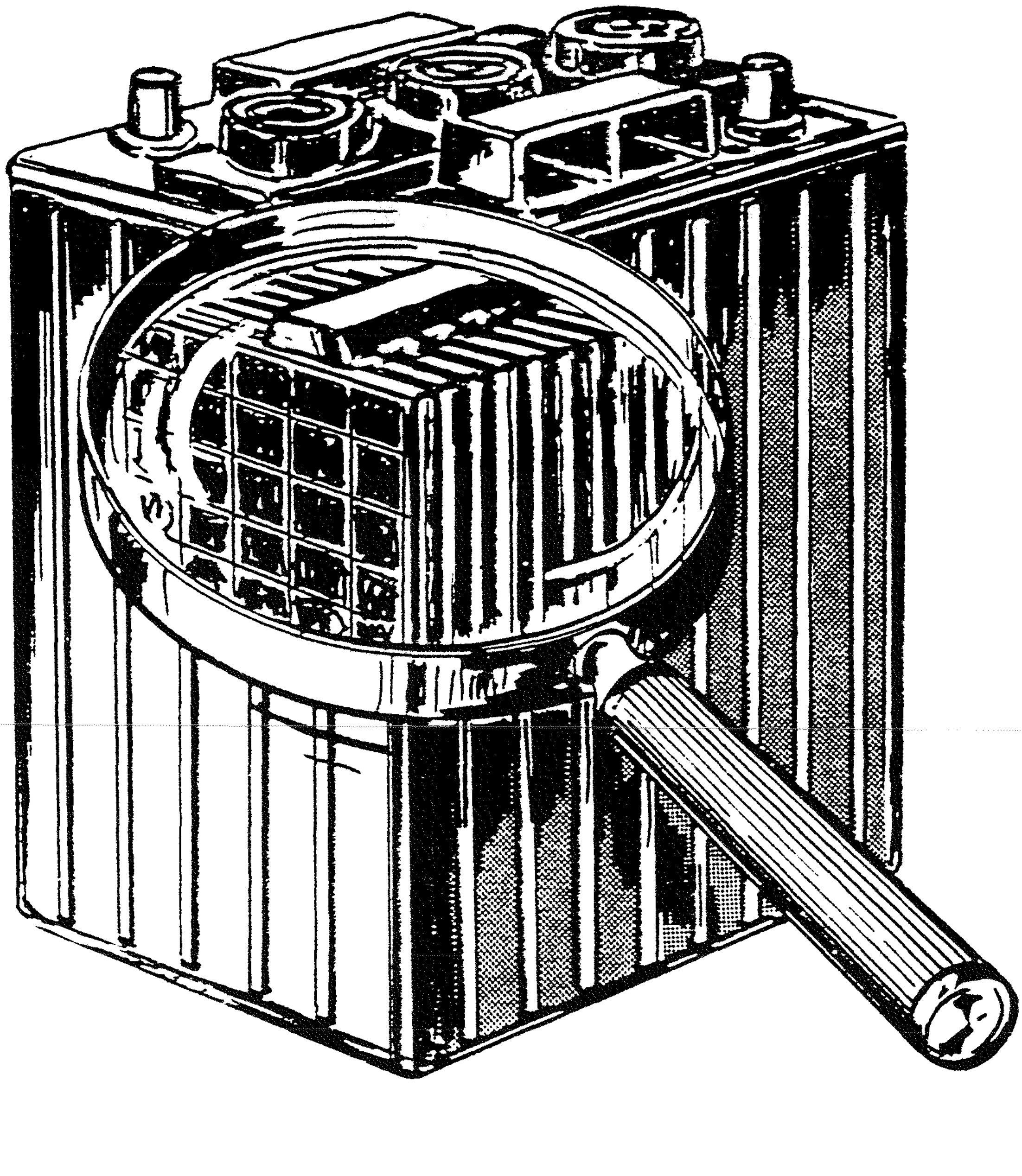
Figur 3. Levetidskurve for det prøvede nikkel-jern batteri (EFP 87)

BATTERITEST
Prøvning og rådgivning

STATENS TEKNISKE PRØVENÆVN
Autorisation nr. 184

BATTERY TESTING
Testing and Consultative Assistance

The Danish National Testing Board
Authorisation No. 184



ENERGILABORATORIET
ENERGY RESEARCH LABORATORY

Autoriseret teknisk prøvning af batterier, godkendt af Statens Tekniske Prøvenævn

Batterier i alle størrelser anvendes i dag i et utal af forskellige sammenhænge - fra startbatterier i biler til energilager i højt specificerede nødstrømsanlæg.
Energilaboratoriet er godkendt af Statens Tekniske Prøvenævn til at udføre autoriseret teknisk prøvning af blysyrebatterier.
Energilaboratoriets erfarne og veluddannede medarbejderstab og vort avancerede prøvningsudstyr sikrer præcise og veldokumenterede måleresultater.
Prøvningsprogrammer kan gennemføres inden for alle anvendelsesområder, hvor bly-batterier indgår som en del af et system.
Prøvningen foretages i henhold til DIN 43539, DIN 72311, IEC 95, IEC 254 forslag 21-242 eller tilsvarende internationale normer samt alment anerkendte prøvningsmetoder.

Prøvningen kan bl.a. omfatte fastlæggelse af:
- Kapacitet
- Levetid (antal op- og afladninger)
- Selvafladning
- Ladebarhed
- Modstandsevne mod vibration
- Effekttæthed
- Energitæthed

Rådgivning

Prøvning alene er ikke nok. Det er vigtigt såvel ud fra et økonomisk som fra et funktionsmæssigt synspunkt, at de tekniske specifikationer for det valgte batteri passer til den givne anvendelse.
Energilaboratoriet udfører derfor ud over autoriseret prøvning rådgivning gennem:
- Udvikling af prøvningsmetoder til enhver anvendelse af batterier
- Prøvning ifølge kundespecifikation
- Beregning, konstruktion og prøvning af komplette drivsystemer til elektriske køretøjer
- Beregning, konstruktion og prøvning af ladeudstyr til alle batterityper

Energilaboratoriet kan herigennem sikre, at det rigtige batteri til den givne anvendelse bliver valgt.

Authorized Technical Testing of Batteries, approved by the Danish National Testing Board.

Today's broad field of battery application encompasses every possible batterytype, from a car's starter battery to energy storage batteries in highly specified UPS systems.
The Energy Research Laboratory is authorized by the Danish National Testing Board to execute technical testing of lead-acid batteries.
Battery testing is performed by skilled staff using advanced equipment, facilitating testing according to all current standards and specifications. Test programmes simulating any field of use for lead-acid batteries can be designed and implemented at the ERL.
The testing is performed according to DIN 43539, DIN 72311, IEC 95, IEC 254 proposal 21-242, or to other international standards as well as other generally approved test methods.
The test programme could comprise the determination of:
- Capacity
- Life time (number of charges/discharges cycles)
- Self discharge
- Charge ability
- Resistance to vibrations
- Power density
- Energy density

Consultative assistance

Testing, however, should not stand alone. It is essential that the technical specifications of the chosen battery suits the application.
The ERL can offer consultative assistance through:
- Development of testing methods for any application of lead-acid batteries
- Testing according to customer specification
- Design, construction and testing of complete electric drivetrains
- Design, construction and testing of charging equipment for all battery types

The Energy Research Laboratory ensures correct battery choice for the specific application.

Batteritest faciliteter

Battery Test facilities

ENERGILABORATORIET *ENERGY RESEARCH LABORATORY*

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APPENDIX B

Subject: SAFT's NICKEL IRON BATTERY

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NICKEL IRON BATTERY COST EVALUATION

1. INTRODUCTION :

SAFT, which has producted industrially, and in large quantities, nickel-iron batteries for traction applications (e.g fork-lift trucks) has undertaken during the last few years the development of a new concept of nickel-iron batteries with high specific energy and energy density, designed especially for the electric vehicle application.

In the short term, only lead-acid and alkaline nickel iron batteries are likely to be developped commercially for the first generation of electric vehicles. In spite of their higher cost, nickel-iron batteries are particulary attractive as their well known characteristics of solidity, reliability, power, deep discharge capability and long cycle life will guarantee that electric vehicles, in an urban use, have a sufficient range together with excellent reliability.

2. MODULE DESIGN :

2.1. General outline

On the basis of the results obtained with the prototype cell two 5-cell modules were designed and developed as is shown in figure 1.

The case and cover are in injection moulded polypropylene. The overall dimensions of the modules are :

	HE 1400	HE 1000
. length (mm)	244	244
. width (mm)	190	155
. height (mm)	280	260
Total weight (kg)	25	18

2.2. Positive electrodes

The positive electrodes are 1 mm thick and made from nickel powder sintered onto a support of perforated nickel-plated stell strip and then chemically impregnated.

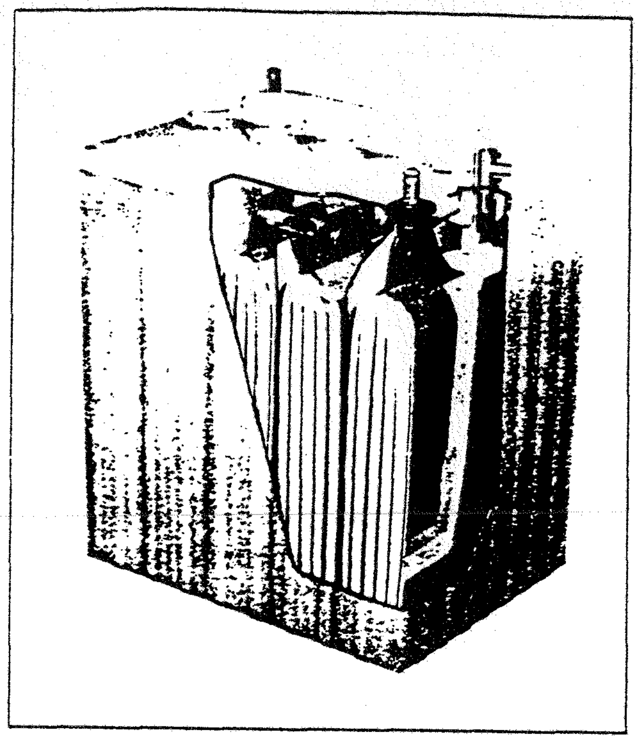

Fig. 1 HE 1400

2.3. Negative electrodes

The negative electrodes, 1.6 mm thick, consist of plastic-bonded iron oxide with an expanded steel substrate. Their width and height are identical to those of the positive electrodes. Electrode nominal capacity is 30 Ah with 10 negatives electrodes per cell.

2.4. Electrolyte - Separator

The electrolyte is a solution of 4.5 N KOH + 1.1 N LiOH.
The separator which is made of a membrane held between two polyamide felts, is wrapped around the negative electrodes.

2.5. Single point watering system

All the cells in a module are equiped with automatic individual filling caps linked to a centralised filling system.
Filling is carried out cell-by-cell from a water reservoir either by gravity or via a pump.
When the upper level is reached, the electrolyte blocks an air-escape hole and an excess air pressure is produced which is sufficient to stop the flow of water into the corresponding cell ; as the caps are linked in series, filling takes place in the next cell and so on up to the last cell.

../...

2.6. Module weight breakdown

The weight (in %) of the different module components are shown in table 2 :

	Weight %
Positive electrodes	45.0
Negative electrodes	23.7
Separator	2.6
Electrolyte	21.5
Case + cover	5.0
Terminals and connections	1.8
Filling caps	0.4
Total module	100.0

Table 2 : module weight breakdown

As may be seen the active components (positive and negative electrodes + electrolyte) represent 90% of the total module weight. In the future, any significant improvent in the specific energy ration of the module will pass by a modification in the electrode concept and principally that of the positive electrodes.

3. PROGRAM HISTORY AND GOALS :

The main results obtained up to the present and the nickel/iron program goals are shown in table 1.

6V-230 Ah module

	1978 55Ah cell	1980 200 Ah cell	1983 prototype module		1986 série module	1990
	Results	Results	Goals	Results	Results	Goals
specific energy (Wh/kg) (a)	45	50	55	60	55	70
Energy density (Wd/dm3) (a)	80	90	110	116	110	130
Peak - power (W/kg) (b)	110	125	150	153	180	185
Energy efficiency (%)	55	55	60	62	60	65
Life (c) :						
. number cycles	1000	1500	1500	under test	1000	2000
. equivalent distances covered in SAEJ227 C cycles (km)	NA	120000	120000	under test	under test 80000	160000

(a) for a 3 hr discharge rate
(b) sustainable for 15 sec at 50% of battery discharge
(c) under cycling at 80% depth - of - discharge, end of life defined as 20% loss of initial capacity

TABLE 1 : RESULTS and GOALS OF THE NICKEL-IRON PROGRAM

4. MONOBLOC EVALUATION

As we manufacture two types of monoblocs the HE 1000 and the HE 1400 we shall express all the data referring the kWh unit.

Today the kWh OEM price is 4750 FF and our plant in Bordeaux is able to produce the monobloc at a rate of 5 monoblocs per day ($\simeq$ 60 EV/year).

With a law investment we can easily reach a level of 10 monoblocs per day ($\simeq$ 120 EV/year). The price will not change.

5. MASS PRODUCTION ESTIMATION

As the monoblocs have been designed in a full automatized production line point of view, we are able to give with a quite good approximation, the evolution of the OEM price versus the production volume.

After a decision point we need 2 years to reach a rate of 50 monoblocs per day. At this step we have a pilot plant using the serie equipment in order to prepare the next step. In the strict economic point of view the 50 monobloc/ day is'nt viable. It shall be considered only as an to equipment to perfect the full automatized line.

At 50 monoblocs/day (600 EV/year) the OEM price will be 2220 FF/kWh. The pilot plant will be installed in our actual Bordeaux factory.
Two years after we will be able to start the mass production in a new plant.

At 1000 monoblocs/day ($\simeq$ 10.000 EV/year) the OEM price will be 1250 FF/kWh.

APPENDIX C

Subject: SAB NIFE's NICKEL-IRON BATTERY

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INSTITUTE OF MICROWAVE TECHNOLOGY

Date 86-05-02

Our ref Bo Andersson

NICKEL/IRON BATTERIES FOR ELECTRIC ROAD VEHICLES

Introduction.

The story of the nickel/iron battery started around the turn of this century when Waldemar Jungner in Sweden and Thomas A Edison in the USA worked out its basic principles. Even at this early stage, one of the main objectives was traction.

Nickel/iron batteries found a widespread use during the first half of this century for traction and deep cycling applications. The batteries were charactericed by long life and high mechanical strength. However, their low specific energy and poor electric efficiency contributed to a declining interest in this battery. In most applications, the original nickel/iron batteries for traction purposes have been replaced by lead-acid batteries.

During the last 30 years, nickel/iron batteries have had a very limited market in the Western world. In the Sovjet Union, nickel/iron batteries of modern design are produced in large quantities.

The energy crisis during the seventies created a renewed interest in traction batteries, mainly for electric road vehicles. Development programs were initiated in many countries with the effort concentrated on improved or advanced batteries compared with the state of the art lead-acid battery. It was soon realized that only a few concepts could be developed in the short term. For example in the USA, the Department of Energy program was concentrated on the improved lead-acid, the nickel/iron and the nickel/zink batteries in this time frame. In this program, the nickel/iron battery has been developed to a level which makes it potentially suitable for electric road vehicles. In Sweden, SAB NIFE AB has been very active in nickel/iron battery development for many years. Several prototype batteries have been manufactured and tested in vehicles for many years in Europe as well as in the USA through a cooperation with Eagle Picher Industries, Inc.

Performance characteristics of modern nickel/iron batteries for electric road vehicles.

Electric road vehicle batteries have to fulfill several requirements if they are to give satisfactory performance, low maintenance costs and a reasonable price for the vehicle.

The nickel/iron battery with sintered electrodes developed by SAB NIFE is based on the principles described earlier(1).

The specific energy is 45 - 50 Wh/kg corresponding to 95 - 100 Wh/l at a 3 hour discharge rate, depending on the cell size and design. The average discharge voltage is 1.23 V per cell.

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The specific power is appr 100 W/kg at 50 % state of charge. The nickel/iron battery has the advantage of delivering high power even at the end of discharge which is very important for the electric vehicle performance. At 20 % state of charge, over 80 W/kg is recorded.

Still another important parameter for EV batteries is the life. The nickel/iron battery is expected to reach 2000 charge/discharge cycles corresponding to 10 years of operation. Real field tests have not yet reached these large cycle numbers. However the first batteries are in service since 1980.

Opportunity charging is expected to extend the total energy delivered by the battery throughout its life. At 1,5 - 2,0 cycles per day the life will be the same in terms of years.

The nickel/iron battery does not need sofisticated charging regimes. High overcharge or high recharge rates is not detrimental to the battery. Normal constant current charging will result in an overall energy efficiency of just above 60 %, resulting in a certain water loss. For this reason the battery is equipped with a central watering system.

The nickel/iron battery may also be discharged completely without damage. It can also be stored for long periods in charged or discharged condition without special attention or maintenance requirements. As the battery has an alkaline electrolyte, there is no risk for freezing.

The low temperature performance has been improved considerably compared with the original nickel/iron batteries. The same situation holds for self discharge.

Extensive laboratory tests and a progressing field test program have demonstrated the feasibility of the nickel/iron battery in electric vehicle applications. The combination of high specific energy and power extends range, more than expected, in the real situation. Under urban driving conditions, the range is 2 - 3 times the range when using lead-acid batteries.

Production capability

The nickel/iron battery manufacturing at SAB NIFE AB is at present not performed on a commercial basis. However the company is operating a pilot plant since several years. The production capacity of this facility is appr 2 MWh per year or 200 EV batteries. Cells of different sizes are available, normally with capacities between 150 and 300 Ah, special sizes are manufactured on request.

In Italy, the SAB NIFE AB subsidiary company is assembling nickel/iron batteries, based on the same technology.

As the nickel/iron battery manufacturing is concentrated on the electric vehicle market, the production is related to the market äcceptance. When compared with the lead-acid battery where manufacturing of EV batteries is often on the margin of the normal production, the costs for the nickel/-iron battery will be higher in small quantities.

Cost calculations

Cost calculations for nickel/iron batteries are based on estimations from the manufacturers. Processes and materials requirements are well known from operations of pilot plants, resultiong in a fairly good accuracy in the cost figures. When it comes to very large scale production, the estimations will depend on how conservative or optimistic the proposals are.

The basis for calculating the cost for nickel/iron batteries in electric vehicles is different compared to its lead-acid counterparts.

The available installed energy is much closer to the nominal than for lead-acid batteries. First of all the capacity is normally calculated for the 3-hour discharge rate. The loss when increasing the rate to 1-hour is comparatively small. Furthermore there is no limitation in utilizing 100 % of the capacity. For practical reasons, however, this is difficult as one has to have some spare energy to get back to the charging station. As the specific power is only little influenced by the state of charge, the vehicle performance is acceptable even at the end of discharge. 90 - 95 % of the installed energy will be available for propulsion.

The life of a nickel/iron battery is much better than its counterpart, the lead-acid system. Laboratory tests have shown that 2000 - 3000 deep discharge cycles might be a reasonable goal. 10 years of operation is used in the calculations. Experience from field tests is also advantageous even if no battery has been in service for more than appr. five years. Storage of nickel/iron batteries is as mentioned above not detrimental.

The ability to accept interim charging or multiple cycles a day is one of the most important advantages for the nickel/-iron battery in electric vehicle applications. As the recharge rate may be shorter than 1-hour, there is a possibility to reach a total of 3 - 4 full cycles a day. In the kind of applications where this is possible, one can install a smaller battery and extend range by interim charging. If the recharge is stopped prior to gassing (eg appr 90 % state of charge) this will not influence life. One cycle is defined as a discharge followed by a full recharge with 10 - 20 % overcharge.

When comparing the specific energy consumption for vehicles equipped with nickel/iron instead of lead-acid batteries of the same size, a lower value is used, (0.25 instead of 0.30 kWh/km).

Finally the nickel/iron battery will have a high scrap value. the main component are nickel and iron of high purity. The scrap material may be used as raw material for stainless steel production. The value of used batteries can be estimated to appr 20 % of the price. This is not considered in the calculations.

Cost data for OEM sales at different production levels is presented in the attached graph. An example of comparison of nickel/iron and lead-acid battery cost per range of 1000 km is presented below for different utilization factors.

		NICKEL/IRON		LEAD-ACID	
battery size (available)	kWh	15		15	
battery life	years	10		5	
working days	days/year	250		250	
energy consumption	kWh/km	0,25		0,30	
production size	MWh/year	10	100	10	100
battery price	ECU/year	500	310	230	150
INVESTMENT COST PER 1000 KM TOTAL RANGE					
utilization of the installed capacity	50 %	100,00	64,00	110,40	72,00
	100 %	50,00	31,00	55,20	36,00
	160 %	31,25	19,38	34,50	22,50
	240 %	20,83	12,92	23,00	15,00
	320 %	15,63	9,69	17,25	11,25

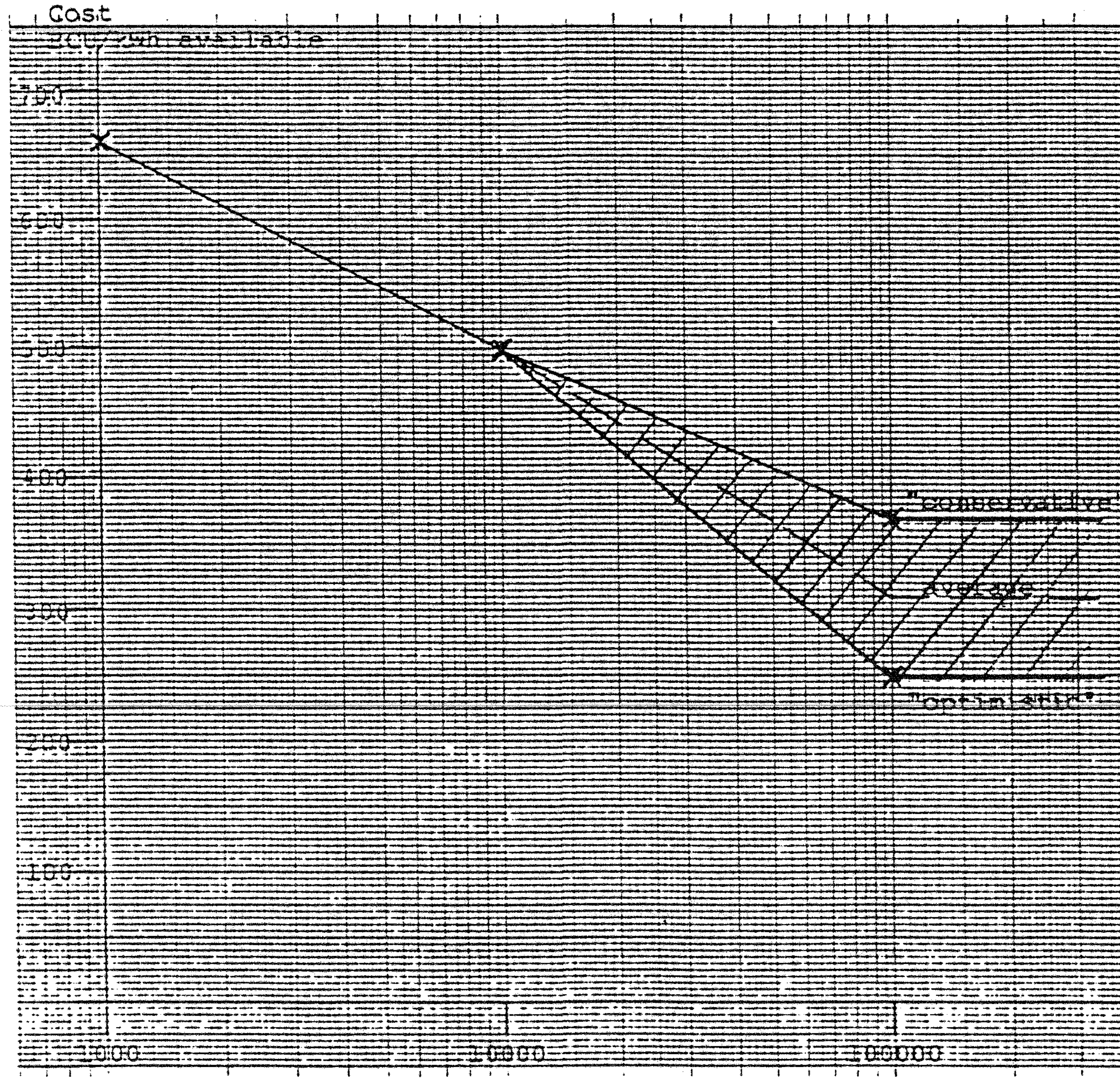
INSTITUTE OF
MICROWAVE TECHNOLOGY

Date 1986-04-18

Our ref . C5
Bo Andersson

ELECTRIC ROAD VEHICLES

COST FOR NICKEL/IRON BATTERIES



annual battery production kWh/year available energy

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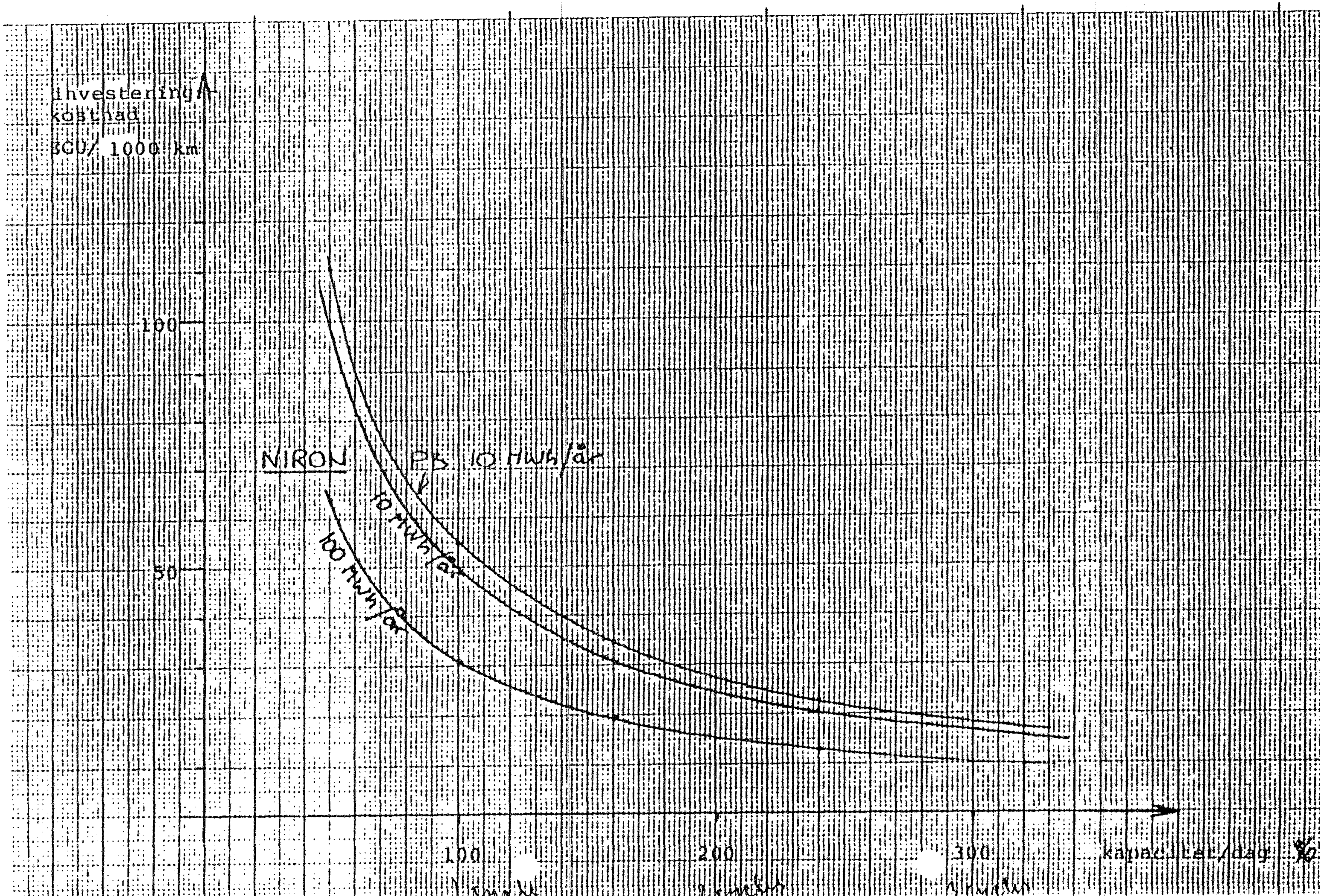
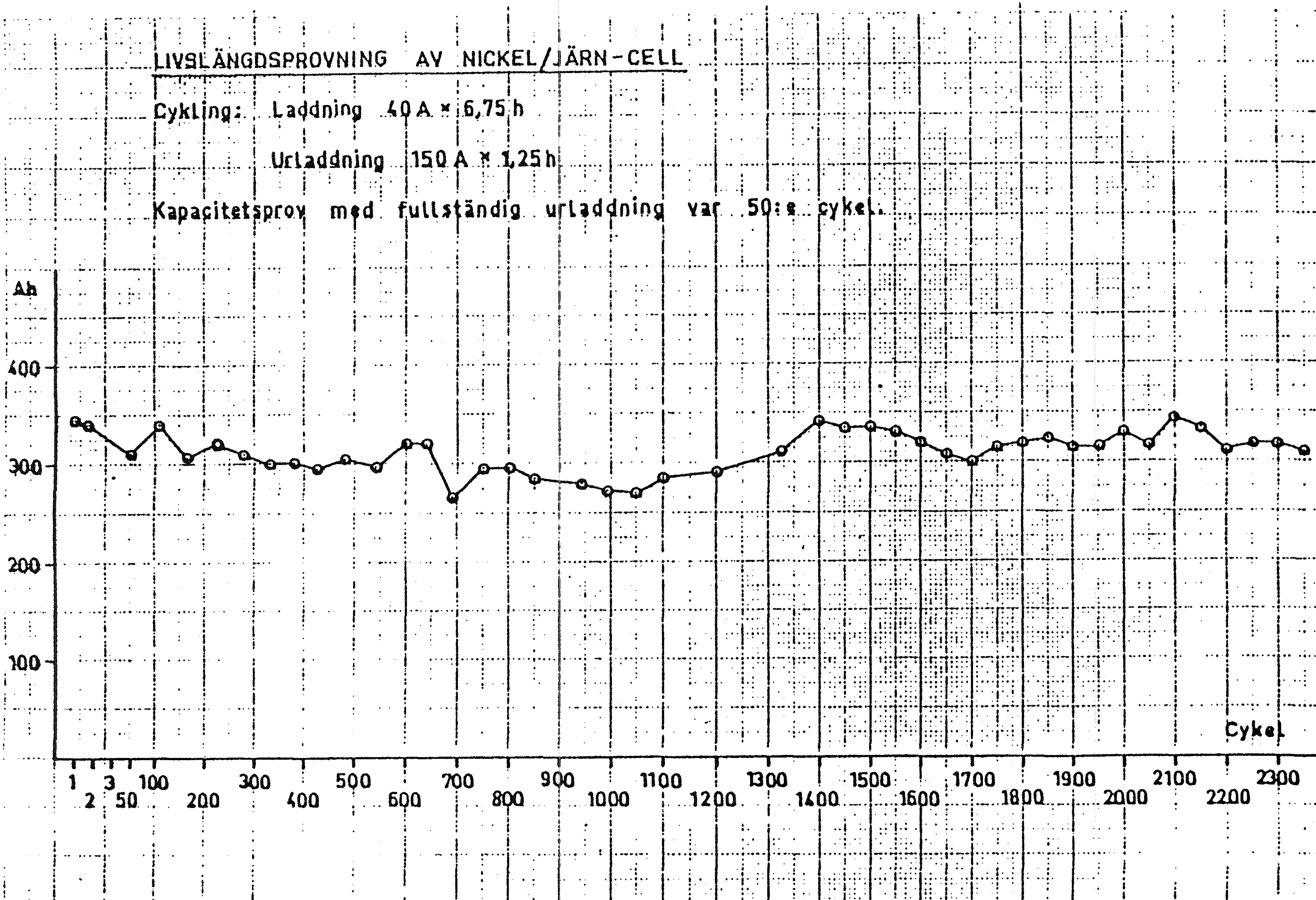

investering/
kostnad
ECU/ 1000 km
100
50
NIRON
Pb 10 MWh/år
10 MWh/år
100 MWh/år
100
200
300
kapacitet/dag

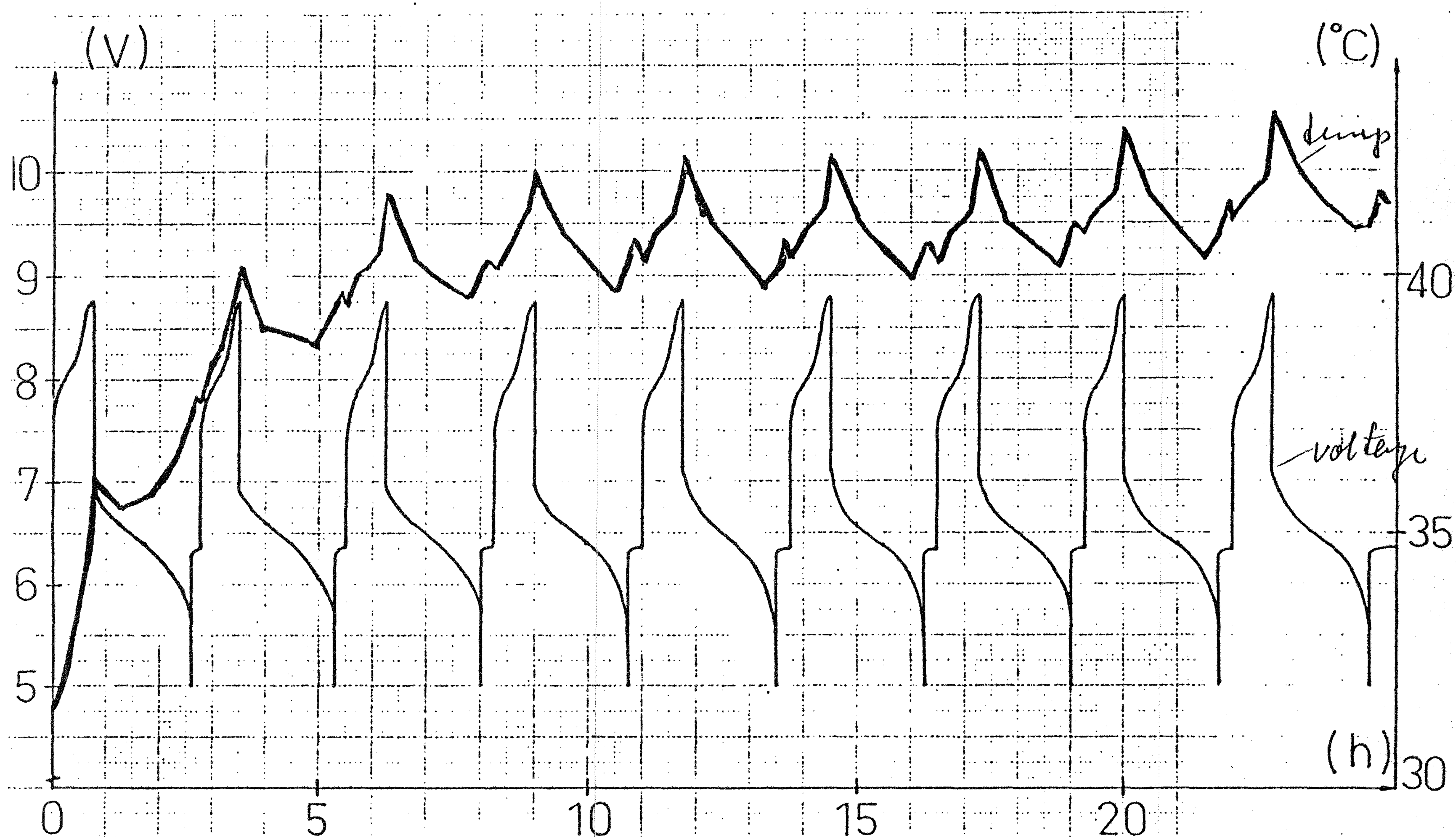
C6


LIVSLÄNGDSPROVNING AV NICKEL/JÄRN-CELL
Cykling: Laddning 40 A × 6,75 h
Urladdning 150 A × 1,25 h
Kapacitetsprov med fullständig urladdning var 50:e cykel.
Ah
400
300
200
100
Cykel
1 2 3 50 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200 2300

T82-042

C7

Ni-Fe

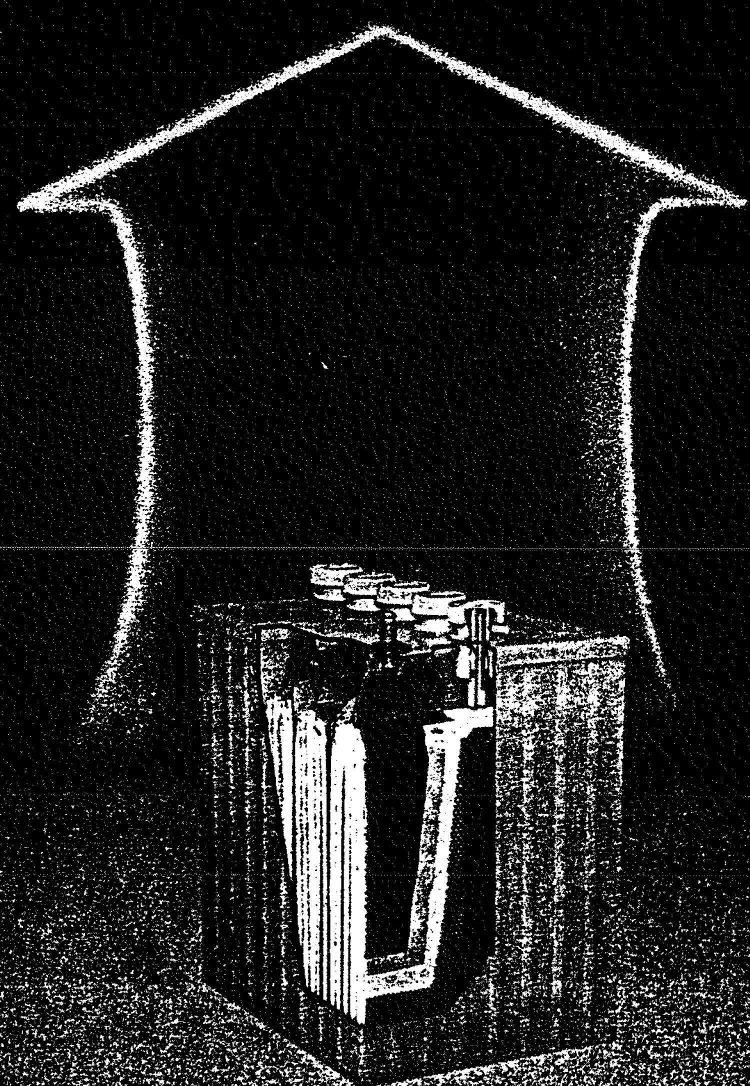


6V monoblock C8

SAFT

DEPARTEMENT ACCUMULATEURS

The future of urban transport : the Nickel-Iron battery



Exceptionally long life - Legendary reliability
Highest ever available energy density

Researches undertaken over many years into electric vehicle applications have enabled SAFT to develop a new generation of Nickel-Iron batteries.

The use of new plate technologies, an ultra-thin separator, the perfection of a connection through the cell wall (previously unknown in alkaline batteries), and the adoption of a centralised watering system give the SAFT Nickel-Iron monobloc battery the best energy density performance ever achieved :

60 Wh/kg 120 Wh/dm^3 170 W/kg

General data

Nominal voltage : 6.25 V
Rated capacity : 230 Ah
Length : 244 mm
Width : 190 mm
Height : 280 mm
Weight : 25 kg

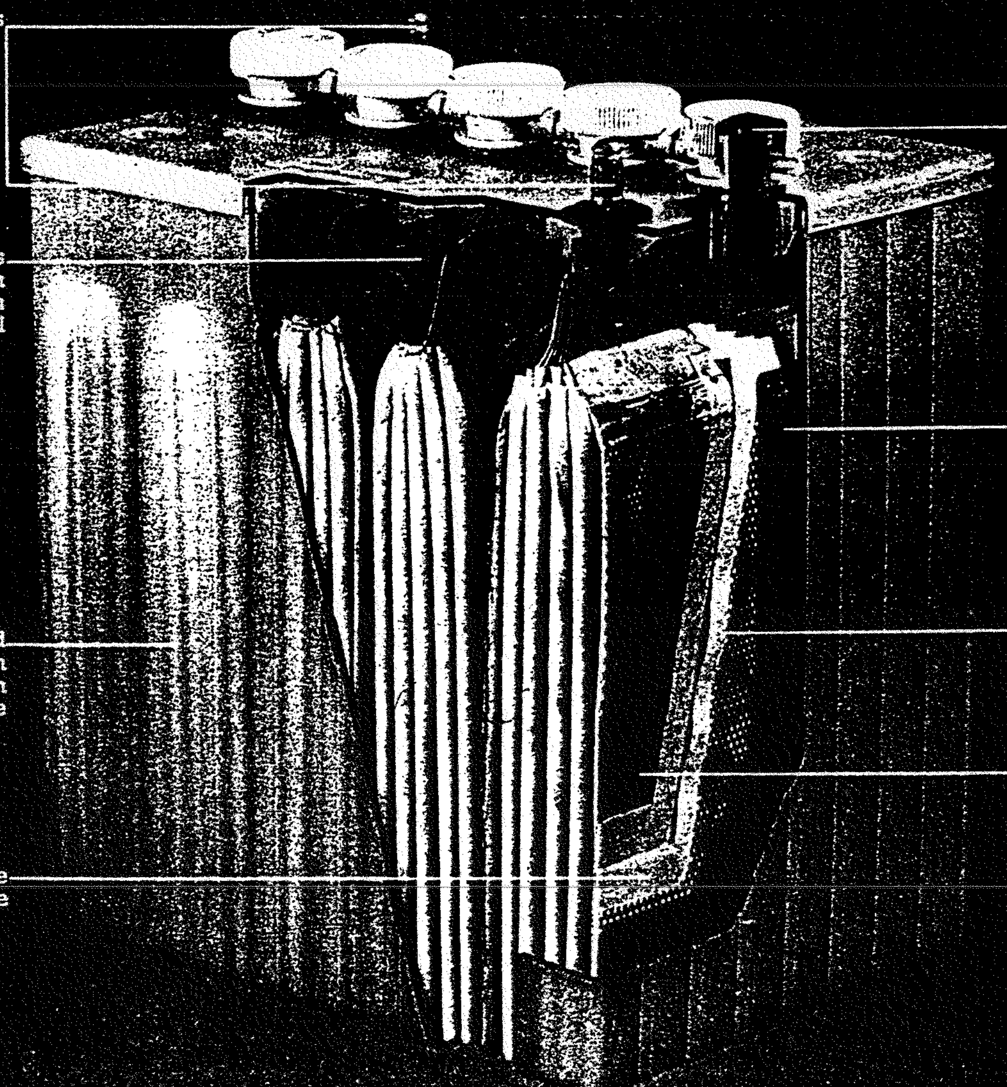
Charging

constant current at 20 °C

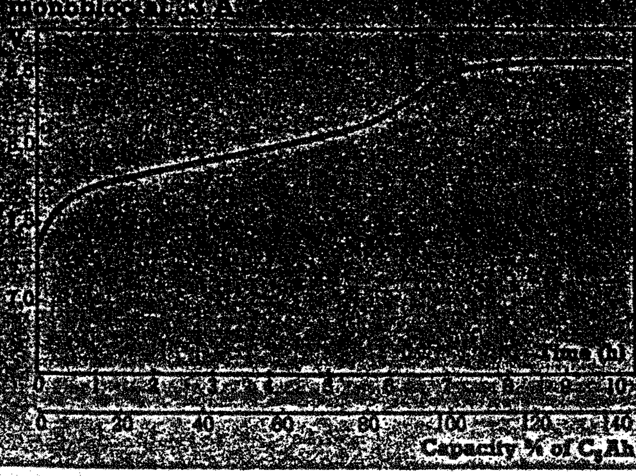
Normal charge : [illegible] h at [illegible] A
Charge limits : 20 A to 50 A
Charge factor : 1.2 to [illegible]
Commissioning charge : 14 h at 33 A

The Nickel-Iron battery

The only battery able to provide the performance required by automobile manufacturers



Charging curve of [illegible] monobloc [illegible]



Charging

Constant potential with current limit at 20°C

[illegible]

To this performance must be added reliability and robustness proven by use over almost half a century :
— life on cycling at 80% depth of discharge reaching 2000 cycles.

And further, the battery with these outstanding features is :
— undamaged by substantial overcharges,
— capable of repeated total discharge,
— able to withstand long period storage in any state of charge.

Charging curve of 8 V 230 Ah monobloc at 8 V with current limit

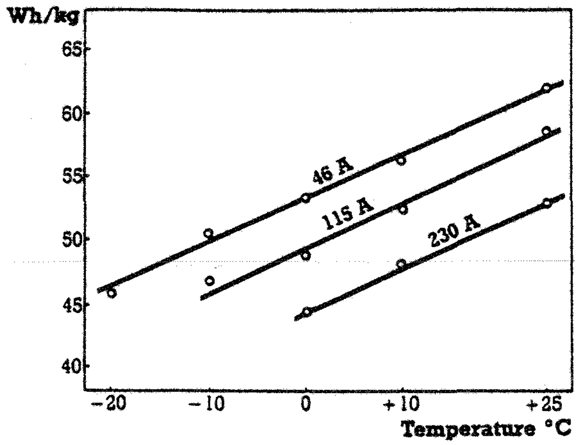
Charging

• *Rapid (top-up) at 20°C*

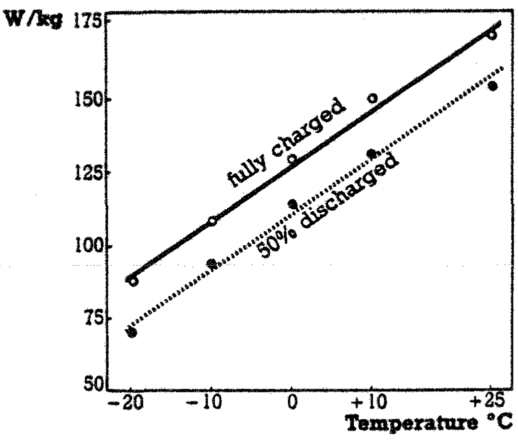
Rapid charges at constant potential (8 V) without current limit may be applied without damage (e.g. with 210 A at start of charge, 80% of capacity is recharged in 2 hours).

Energy density and power density

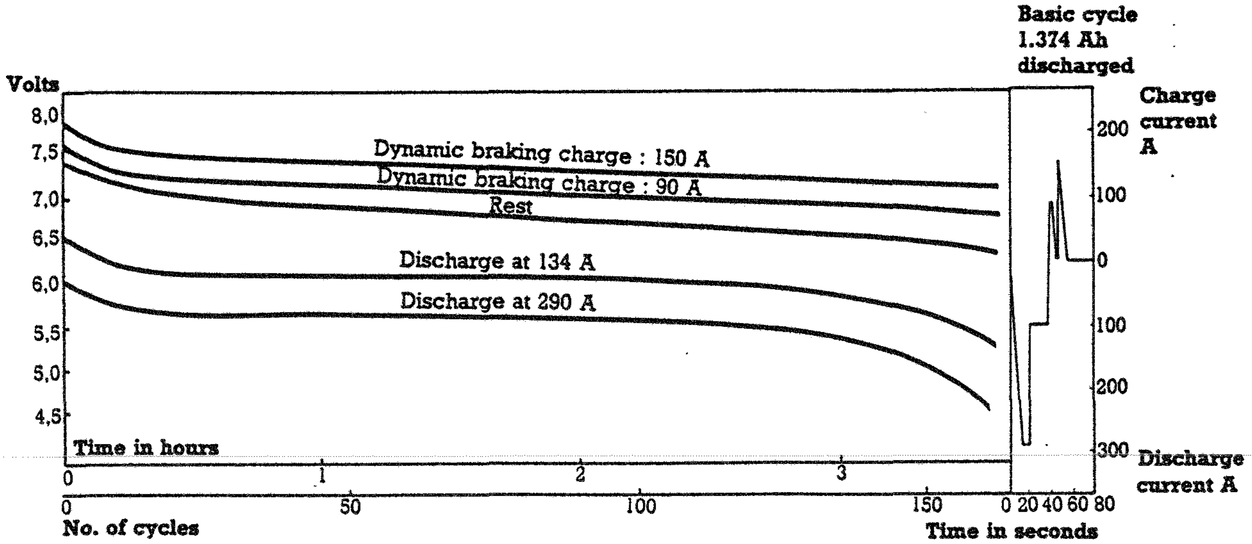
Specific energy/temperature for various rates of discharge



Specific power/temperature at various states of charge



Discharge to SAE specification J 227 aC



SAFT
DEPARTEMENT ACCUMULATEURS

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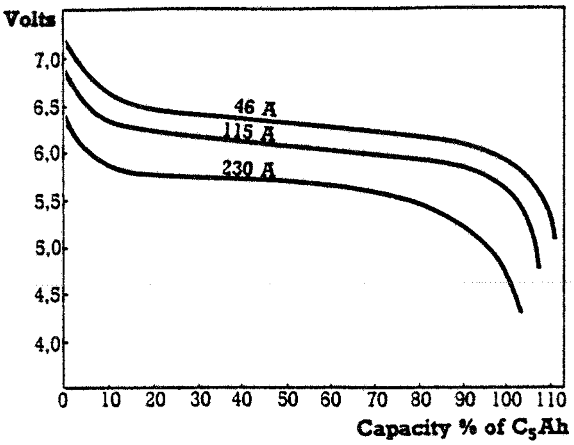
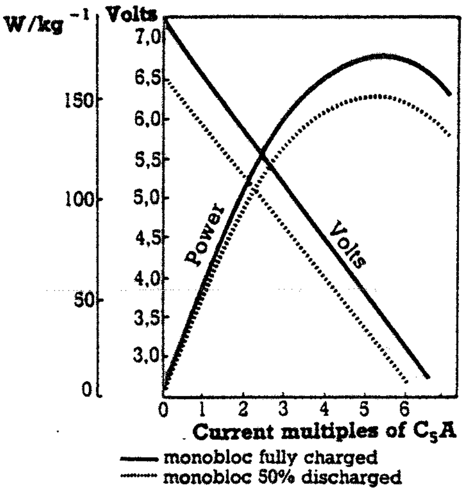
:-10-84-1439-2

Discharge curves of 6 V - 230 Ah monobloc

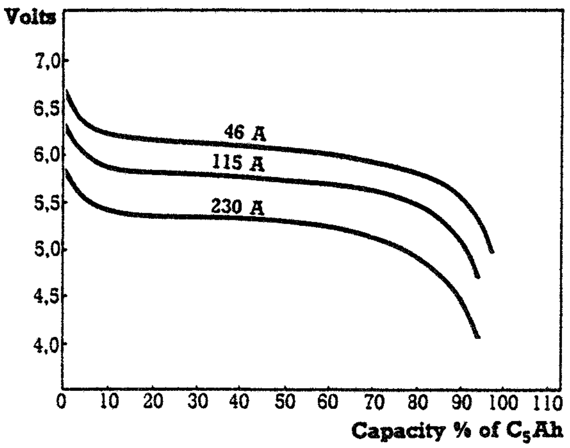
Discharge at various rates at 20°C



Peak discharges-15 sec. at 20°C



Discharge at various rates at 0°C



Peak discharges 15 sec. at 0°C