Vegdirektoratet
Trafikksikkerhet, miljø- og teknologiavdelingen
Tunnel og betong
Mai 2016

Statens vegvesen

Energieffektive tunneler - ENERTUN - D2.2

Etatsprogrammet Varige konstruksjoner 2012-2015

STATENS VEGVESENS RAPPORTER Nr. 555

Statens vegvesens rapporter

NPRA reports
Norwegian Public Roads Administration

Tittel
Energieffektive tunneler - ENERTUN - D2.2

Undertittel
Investigation on electrical consumption in road tunnels in Norway and Spain

Forfatter
Daniel Octavio de Toledo, Geocontrol

Avdeling
Trafikksikkerhet, miljø- og teknologiavdelingen

Seksjon
Tunnel og betong

Prosjektnummer
603242

Rapportnummer
Nr. 555

Prosjektleder
Synnøve A. Myren / Harald Buvik

Godkjent av
Harald Buvik

Emneord
Varige konstruksjoner, fremtidens tunneler, ENERTUN, energieffektive tunneler, strømforbruk

Sammendrag
Denne rapporten er den tredje av totalt seks rapporter fra et to-årige FoU-samarbeid Varige konstruksjoner har med det spanske engineering-selskapet Geocontrol. Samarbeidet er rettet mot utvikling av energieffektive tunneler gjennom prosjektet ENERTUN som Geocontrol leder. ENERTUN gjennomføres i regi av EEA GRANTS, en samarbeidsorganisasjon der EØS-landene Norge, Island og Lichtenstein gir midler og tilskudd (via Innovasjon Norge) til 16 EU-land i Sentral- og Sør-Europa.

Rapporten gir en oversikt over forskjellen i strømforbruk om sommeren og vinteren og plassering i forhold til inngangssonen. Det er sett på forholdet mellom strømforbruk og ÅDT med variasjoner mellom helg og ukedager og om forbruksvariasjon kan knyttes til ventilasjonssystemet.

Antall sider 16
Dato Mai 2016

Title
Energy efficiency in tunnels- ENERTUN - D2.2

Subtitle
Investigation on electrical consumption in road tunnels in Norway and Spain

Author
Daniel Octavio de Toledo, Geocontrol

Department
Traffic Safety, Environment and Technology Department

Section
Tunnel and concrete

Project number
603242

Report number
No. 555

Project manager
Synnøve A. Myren / Harald Buvik

Approved by
Harald Buvik

Key words
Durable structures, future tunnels, ENERTUN, energy efficient tunnels, power consumption

Summary
This report is the third of a total of six reports from a two-year R&D collaboration Durable structures have with the Spanish engineering company Geocontrol. The partnership is aimed at developing energy efficient tunnels through the project ENERTUN as Geocontrol leads. ENERTUN is pursued by the EEA GRANTS, a cooperative organization where the EEA countries Norway, Iceland and Lichtenstein provides funds and grants (via Innovation Norway) for 16 EU countries in Central and Southern Europe.

The report provides an overview of the difference in power consumption in summer and winter and location relative to the entrance zone. It is looked at the relationship between power consumption and AADT with variations between weekend and weekdays, and about consumption variation may be linked to the ventilation system.

Pages 16
Date May 2016

Forord

Denne rapporten inngår i en serie rapporter fra **etatsprogrammet Varige konstruksjoner**. Programmet hører til under Trafikksikkerhet-, miljø- og teknologiavdelingen i Statens vegvesen, Vegdirektoratet, og foregår i perioden 2012-2015. Hensikten med programmet er å legge til rette for at riktige materialer og produkter brukes på riktig måte i Statens vegvesen sine konstruksjoner, med hovedvekt på bruer og tunneler.

Formålet med programmet er å bidra til mer forutsigbarhet i drift- og vedlikeholdsfasen for konstruksjonene. Dette vil igjen føre til lavere kostnader. Programmet vil også bidra til å øke bevisstheten og kunnskapen om materialer og løsninger, både i Statens vegvesen og i bransjen for øvrig.

For å realisere dette formålet skal programmet bidra til at aktuelle håndbøker i Statens vegvesen oppdateres med tanke på riktig bruk av materialer, sørge for økt kunnskap om miljøpåkjenninger og nedbrytningsmekanismer for bruer og tunneler, og gi konkrete forslag til valg av materialer og løsninger for bruer og tunneler.

Varige konstruksjoner består, i tillegg til et overordnet implementeringsprosjekt, av fire prosjekter:

Prosjekt 1: Tilstandsutvikling bruer
Prosjekt 2: Tilstandsutvikling tunneler
Prosjekt 3: Fremtidens bruer
Prosjekt 4: Fremtidens tunneler

Varige konstruksjoner ledes av Synnøve A. Myren. Mer informasjon om prosjektet finnes på vegvesen.no/varigekonstruksjoner

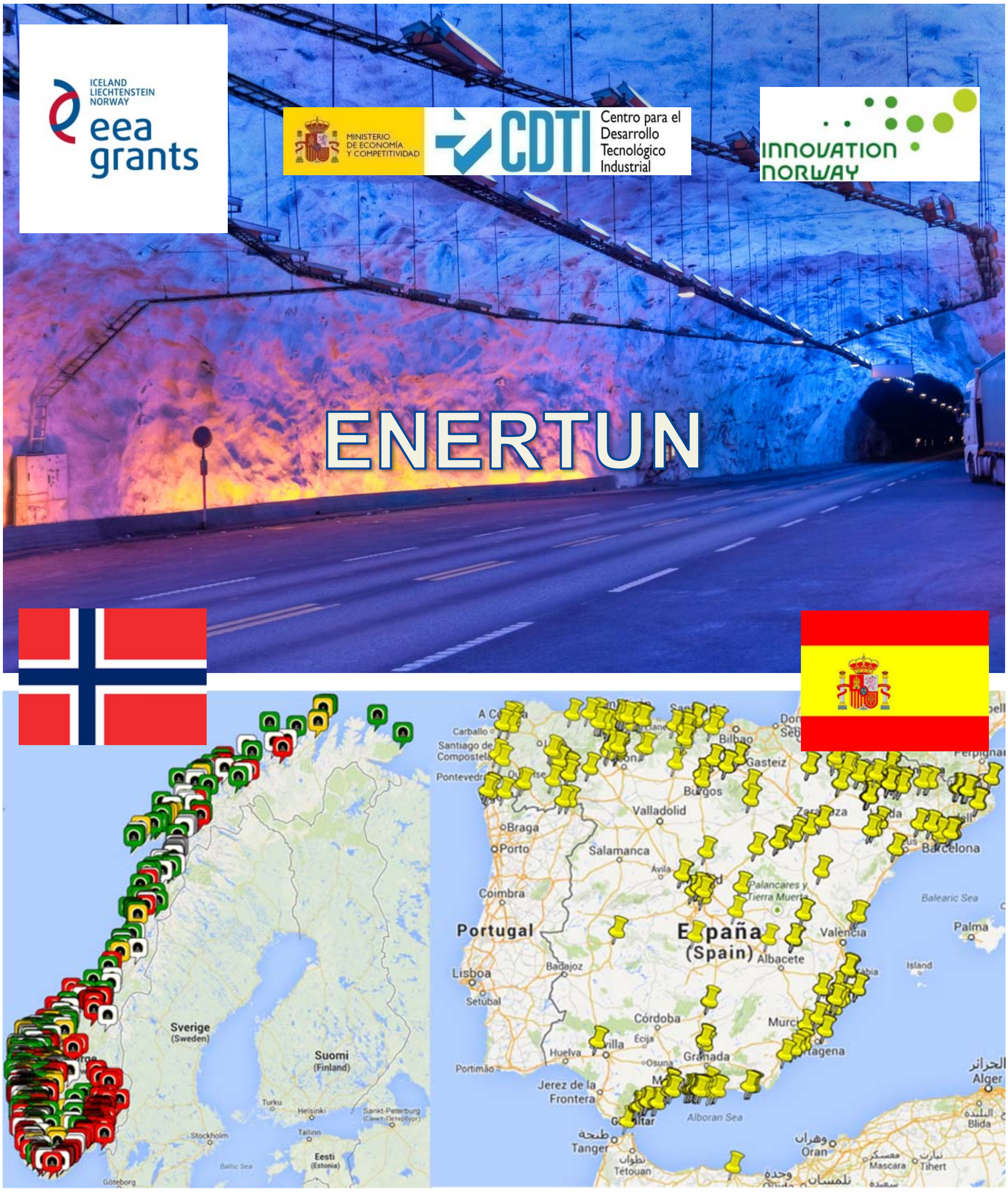
Denne rapporten tilhører **Prosjekt 4: Fremtidens tunneler** som ledes av Harald Buvik. Prosjektet skal bidra til at fremtidige tunneler bygges med materialer, utførelse og kontroll bedre tilpasset det miljøet konstruksjonene er utsatt for. Prosjektet skal bygge videre på arbeidet i Moderne Vegtunneler, samt innspill fra Prosjekt 2: Tilstandsutvikling tunneler, med hovedfokus på tunnelkonstruksjonen i et levetidsperspektiv. Prosjektet skal resultere i at installasjoner i fremtidige tunneler oppnår tiltenkt levetid med reduserte og mer forutsigbare drift- og vedlikeholdskostnader.

Rapporten er utarbeidet av *Daniel Octavio de Toledo, Geocontrol*.

EFICIENCIA ENERGÉTICA EN TÚNELES
ENERTUN
ENERGY EFFICIENCY IN TUNNELS

Statens vegvesen

GEOCONTROL
Cristóbal Bordiú 19-21, 5º. 28003 Madrid · T. 91 553 1763 · F. 91 554 9396
geocontrol@geocontrol.es · www.geocontrol.es



DELIVERABLE 2.2.- INVESTIGATION ON ELECTRICAL CONSUMPTION IN ROAD TUNNELS IN NORWAY AND SPAIN

	Written by	Revised by	Approved by
Name:	Daniel Octavio de Toledo (DOT)	Fernando Portugués (FPS)	FP/HB
Date	18/09/2014	18/09/2014	18/09/2014
File:	1411_deliverable_d2.2_v00_r00		

ENERTUN
DELIVERABLE 2.2.- INVESTIGATION ON ELECTRICAL CONSUMPTION IN ROAD TUNNELS IN NORWAY AND SPAIN

INDEX

ENERTUN
DELIVERABLE 2.1.- MATHEMATICAL MODEL FOR ELECTRICAL CONSUMPTION IN ROAD TUNNELS IN NORWAY AND SPAIN

1. INTRODUCTION.

The electricity bills collected from the Spanish road tunnels network and the energy expenditures provided of the Norwegian road tunnels provide useful information about the energy consumption, but not about the equipment installed in every tunnel.

The temporary variations of the energy consumption provide information about the sources of expenditure; for example, the difference between the consumption of the months during the summer and the winter may be a tool to estimate in which measure the lighting system located in the entrances of the tunnel contributes to the global energy expenditure.

In the case of road tunnels with variations of traffic density throughout the whole week, the variations between working days and weekends might give an idea of the proportion of the energy expenditure linked to the ventilation system.

Anyway, those data are rather imprecise indicators of the source of the consumption and, therefore, they cannot be used for creating a mathematical algorithm.

In order to increase the accuracy and to ensure the preservation of all details in the mathematical model, more precise data are needed, and so for its source. All data collected so far have been obtained through the electricity bills and daily consumptions.

Thus, in order to get the necessary data, measure equipment is required, both for registering the global expenditure and for determining its source.

Current commercial consumption registering units are oriented towards collecting a large number of parameters of just a few circuits, whereas in a tunnel it’s rather more important to collect a few parameters about plenty of circuits. This way, it has been required to design a registering unit particularised for this project needs.

2. DESIGN REQUIREMENTS

The registering unit has been designed to respect the following requirements:

Easy installation without modifying the electrical installation aimed to be analysed.

- Easy transport with no need of auxiliary equipment.
- Capacity of measuring both intensities and voltages and to obtain the energy consumption based on those values. The commercial units able to perform this kind of work are the network analysers.
- Capacity of detecting the activation of every single circuit. In order to do this task with commercial equipment, it should be required modules with digital inputs and a wide set of adaptation units, in order to adapt the circuits' working voltages to the voltage of the modules with digital entries.
- Capacity of increase to integrate other equipment's measures, such as anemometers, thermometers, cinemometers, photocells, and other environmental and traffic sensors. This requirement is easy to meet if the system has a standard communication bus.
- It has to provide registering capacity for several months and/or have the remote transmission systems such as a GSM modem. Commercial units with these functions are denominated dataloggers, but the automated logic controllers could also perform this work.
- The system must maintain the registered data face power outages. Most of the commercial dataloggers verify this requirement, while the automated logic controllers don't.

3. COMMERCIAL ALTERNATIVES

Once the design criteria have been established, it has been needed to contact the technical assistance departments of several manufacturers to make a request about the possible combination of different units to meet the requirements.

The following table presents a summary of the proposed alternative solutions:

MANUFACTURER	Equipment	Network analyser and Quality	Intensity probes	Circuit Activation	Amplification	Type of Memory Registrations	Modem	Cost
ABB	It hasn't sent any proposal							
CIRCUTOR	EDS-3G CVM-V10	Analyser Qualty	Transfor	I/O Digital	Modbus	SRAM 250MB	3G	Reasonable
	EDS-3G CVMNET4	x4 A Calidad	Transfor	I/O Digital	Modbus	SRAM 250MB	3G	High
	AR6	A Calidad y Eventos	Flexible	NO	NO	Tarjeta SD Años	NO	High
IAC	S203-D	Analyser Qualty	Flexible	NO	NO	NO	NO	Economic
Microcom	Hermes-200	NO	NO	I/O Digital	Modbus	SRAM 40000Reg	3G	Economic
Schneider	It hasn't sent any proposal							
Socomet	Diris A-40 Datalogger	Analyser Quality	Transfor	I/O Digital	Modbus	Unknown	3G	High

None of the alternatives verify all the desired requirements, highlighting:

- Only the analysers AR6 of CIRCUTOR and S203-D of IAC can be easily installed without the need of modifying the installation, due to the fact that they are the only alternatives that use flexible intensity probes.

- None of the alternatives allows circuit activation detection easy to install without previous knowledge of the electric switchboards' operation and without the need of introducing small modifications.

4. DEVELOPMENT OF A SYSTEM FOR ACTIVATION DETECTION

When it comes to determining which installations are responsible of the global energy consumption of the tunnel, there are two options:

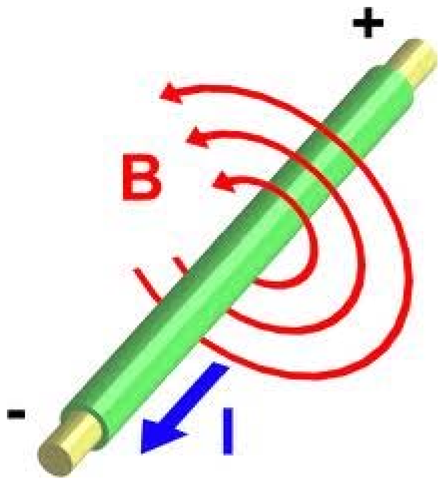
- Monitoring the expenditure of every single circuit. This option requires a network analyser in every circuit, what means a high cost and a high complexity of the installation.

- Monitoring the global expenditure of the installation and registering the state of activation or not of every circuit. This way, only a single network analyser and a single circuit activation detection system are required. Although less data are collected, the same information can be obtained with respect to the first option provided the consumption of the monitored circuits is constant through the time.

In most of the cases, the energy expenditure of the installed circuits in the tunnels presents little variations throughout the time for activation in such a manner that often, the second option is chosen.

With respect to monitoring the circuit activation, some commercial alternatives are available, based on cards with digital inputs that have to be electrically connected to the monitored circuits, through voltage conversion modules. However, this system needs to be electrically connected to the installation, which means being forced to introduce small modifications in this installation and also to provide a high quantity of electrical cables working in the same level of the voltage supply.

Since the activation detection systems are considered rather complicated to install, a new one was due to be created, so that it would be possible to detect a single circuit's activation by measuring the magnetic field produced by the intensity circulating through the chosen circuit. This way, the installation would consist in placing this sensor on one of the electrical conductors of the circuit aimed to be monitored, without the need of electrical connexion.



$$B = \frac{\mu_o i}{4\pi}\int_{-\infty}^{+\infty}\frac{sen\theta}{r^2}dy = \frac{\mu_o i}{4\pi R}\int_0^{\pi} sen\theta \cdot d\theta = \frac{\mu_o i}{2\pi R}$$

If we establish a lower limit for detection of electrical charges of 1000 W (with 220V power supply) and under the assumption that the sensor isn't further than 3,75 mm of the conductor's centre, the magnetic field reaches values of 0,2 µTesla or 2,3 mGaus.

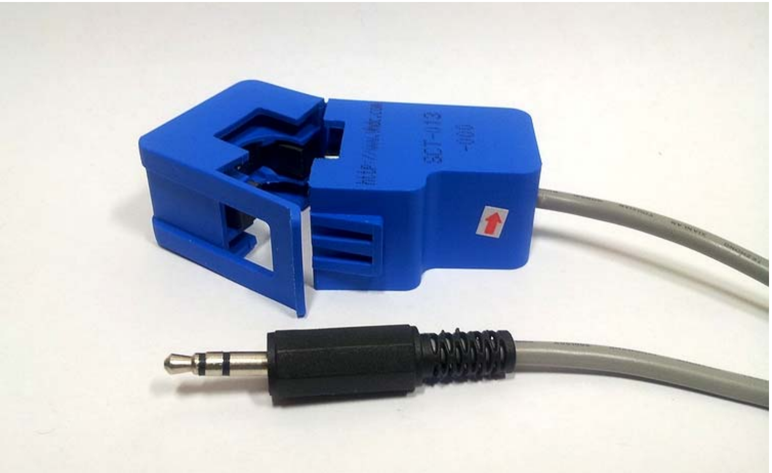
These values are very low to be detected directly with conventional Hall Effect sensors, needing to concentrate the flow with ferrite cores for its detection.

Conventional Hall effect detector	Hall Effect detector + ferrite core
	

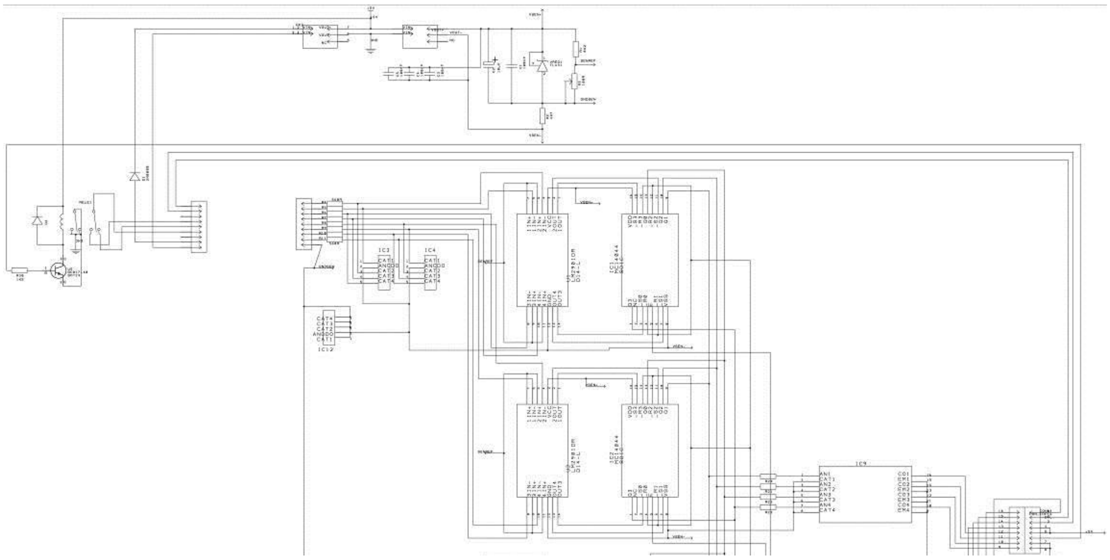
The option involving a ferrite core is ruled out, since for its installation it should be needed to disconnect the cable aimed to monitor as well as in the case of a standard intensity transformer.

However, there are currently available intensity transformers with its core split that, although they offer low precision, they are quite easy to install and have a competitive price, being ideal for our objective, since it’s not required to quantify the intensity with much accuracy.

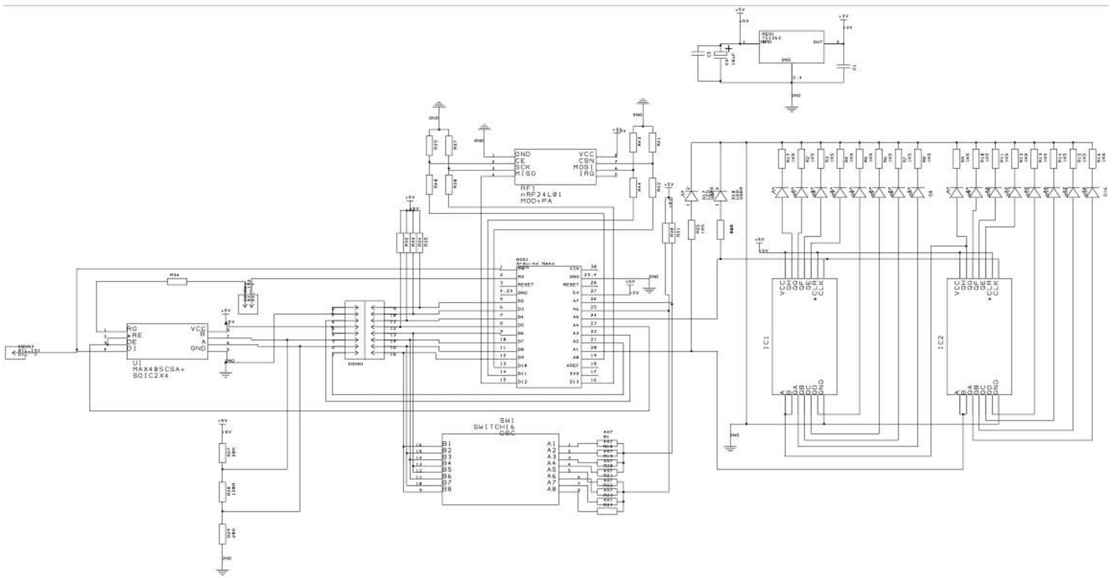
More particularly, the model SCT013-030 of YHDC was chosen, which generates a 1V voltage when detecting intensities of 30 A.



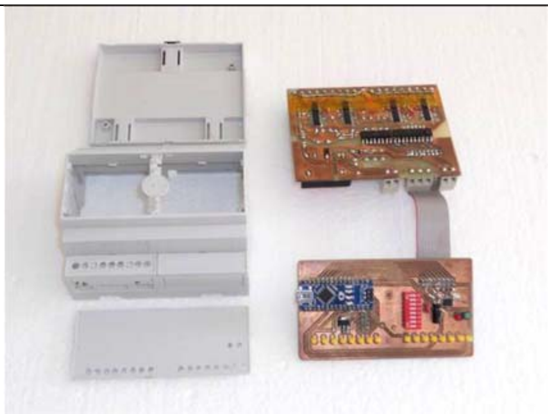
The signal sent by this sensor has to be filtered, compared with a reference value and monitored continuously; for this reason, an electronic circuit, able to process the signal from 16 sensors was designed.



Another additional electronic circuit based on a micro controller Atmel was designed, in order to show the monitoring of the sensors to the users thanks to the lighting of some LED pilot light and also to communicate the state of activation to the equipment in charge of the registering, with a bus Modbus.



Both circuits were implemented in both plaques of printed circuit, integrated inside a box for its assembly over DIN rails.

The characteristics of the designed equipment are the following ones:

- Channels: 16
- Sensibility: adjustable in the range 0,5-1 Ampere.
- Refresh-time: 0,5s in LED's, 1s in Modbus.
- Available data per channel: instantaneous update and accumulated performance.
- Available data in general: Flag of change in any channel.
- Digital outputs: 1 with relay.
- Communication: Modbus RTU with RS485 (command 0x03).
- Communication parameters: 9600 Baud, 8 bits without parity, 1 bit of stop, nº of slave configurable.
- Voltage supply: range 9-30 V DC.
- Consumption: 3W maximum.
- Electrical isolation: 1000V minimum among intensity sensors, communications bus and equipment supply.
- Enlargement possibilities: installation of a clock in real time RTC, microSD card reader, radio frequency transmitter.
- Firmware: update possible with USB port.

5. MULTI-MANUFACTURER ALTERNATIVES

Given that there is no manufacturer that provides equipment with the desired characteristics, it's chosen to undertake a multi-manufacturer solution, for which the following alternatives are considered as interesting:

- Network analyser S203-D with Hermes-200 datalogger: this is the less expensive option and permits to vary the registering period dynamically.

- Network analyser S203-D with datalogger EDS-3G: it includes web server in the datalogger itself, great capacity of storage and permits changing the configuration remotely.

Since both solutions are quite interesting and the final aim is monitoring several tunnels (among which there are several with more than one transformation centre), it is chosen to manufacture both solutions, under the name of consumption supervisor V1 and consumption supervisor V2, respectively.

Due to the fact that both previous solutions don't have the required capacity to measure the electrical quality of the supply and the consumption, it's decided to acquire an AR6 equipment as well, which is specialised for the supervision of the electrical quality. As the electrical quality parameters don't have significant changes throughout the time, this unit (which will be called quality supervisor) will be kept registering data only during the installation process or during the withdrawal of the equipment for the consumption measurement.

6. MANUFACTURE OF THE SUPERVISOR EQUIPMENT FOR CONSUMPTION V1

First of all, the supervisor equipment for consumption V1 is manufactured, to get advantage and use the knowledge acquired for the manufacture of the supervisor equipment V2.

The equipment is based on the following components:

- A network analyser S203-D from the Italian manufacturer SENECA, provided in Spain by IAC.

- An activation detector of up to 16 channels designed by GEOCONTROL specifically for this project.

- A datalogger with 3G modem, model Hermes-200 from the Spanish manufacturer Microcom.

All the equipment previously mentioned work with direct current, thus it is required having a power source to convert the voltage supply (230 V AC) into a common voltage for the analyser, the detector and the datalogger.

A power source UPS1212 from Microcom is chosen due to the fact that, with a 12 V battery, it is also used as a system for uninterrupted power supply and at the same time, provides a signal which is compatible with the datalogger that reports any failure of power supply.

This way, in case of power supply failure of the supervisor equipment, an alarm can be sent through a sms message to the closest technical staff person, while the equipment will keep on working and registering data. The autonomy time is higher than 1 hour, with the chosen battery.

It's foreseen as well to have a protection switch for the battery with double function: it's a protection face short circuits and also a way to disconnect the equipment once it's been uninstalled.

In order to facilitate the transport of the equipment, a light plastic suitcase is due to gather all the elements that integrate the equipment, in which some DIN rails will be installed.

The elements inside the suitcase must be connected to the exterior probes and to the power supply.

Also, the following connection elements between the equipment probes and the suitcase have to be provided:

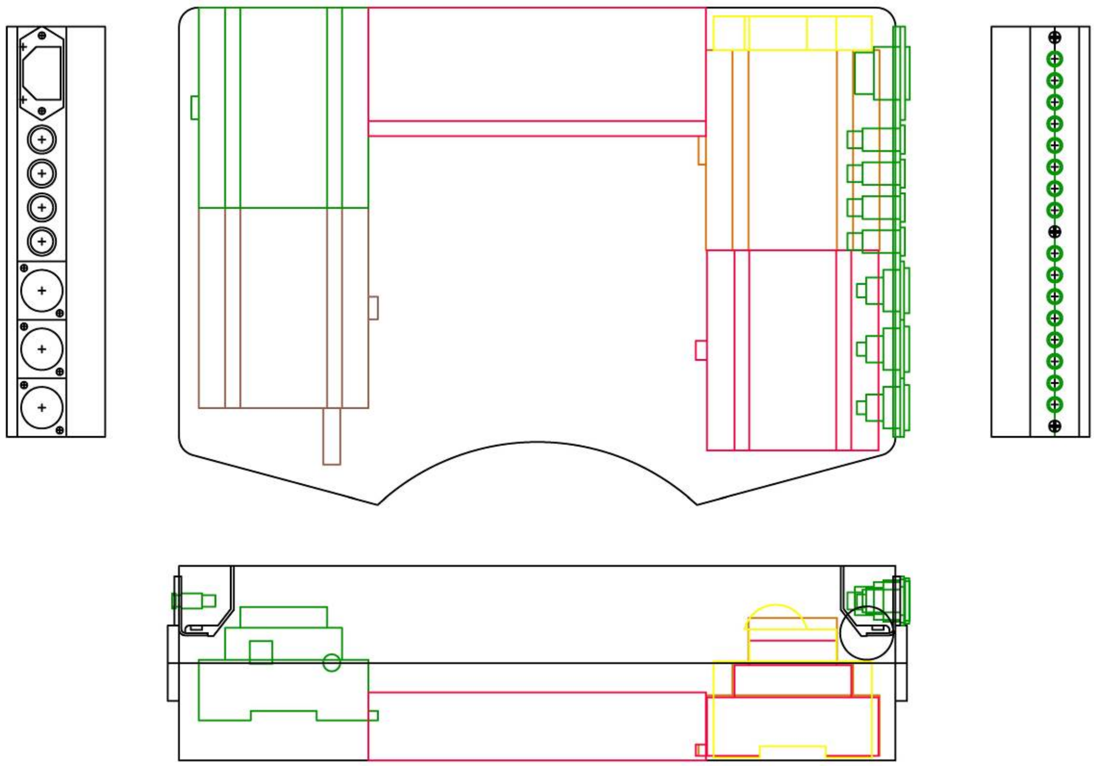
- A C14 connector is chosen for power supply, widely used in Europe.

- Connectors of 4mm and large safety alligator clips are chosen for the connection of the voltage probes, commonly used in measuring units since they permit the connection without any electric risk.

- Gold – plated RCA connectors with low voltage losses are employed for the connection of the intensity probes.

- 3,5mm Jack connectors are employed for the connection of the activation probes, which are provided by their manufacturer. This sort of connection has the advantage that it's easy to find extension cables which are compatible with audio equipment suppliers.

Before the acquisition of all the chosen elements, they are due to be represented in a plan in order to verify the possibility of their assembly in the available space inside a suitcase.



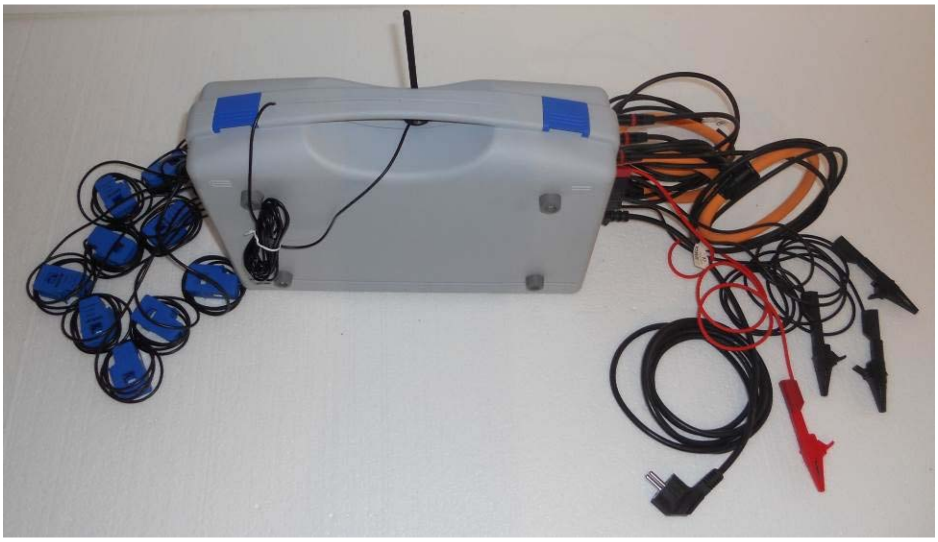
Once the assembly is verified, the following tasks are due to be completed:

- Acquisition of the elements that integrate the equipment.
- Verification of the real dimensions and update of the assembly in the plans.
- Machining of the suitcase and installation of the DIN rails.
- Installation of the elements in the suitcase.
- Electrical connections.

The result is presented in the following images:

The equipment can work without any problem if the suitcase is closed, which facilitates its placement in existing spaces inside the electric switchboards. It's only required the installation of the modem antenna in a place with the necessary network coverage.



The equipment, composed of 10 activation probes, 3 intensity probes, 4 voltage probes and the suitcase, weighs 5,5 kg. However, for more complex installations, 6 additional activation probes and several electric cables should be added, which would mean an additional kg to the total weight.

Although the equipment is physically complete, it must be configured before initialising the registering of the data energy consumption parameters.

7. CONFIGURATION OF THE SUPERVISOR EQUIPMENT OF CONSUMPTION V1 AND ITS SERVER

So as to the equipment to be prepared for the registering of the data, the datalogger is configured with the following parameters:

- Introduction of the SIM data card and configuration of the provider of telephony, messaging and internet services.

- Configuration of the parameters of communication of the bus Modbus and verification of the data transmission between the datalogger and the slaves.

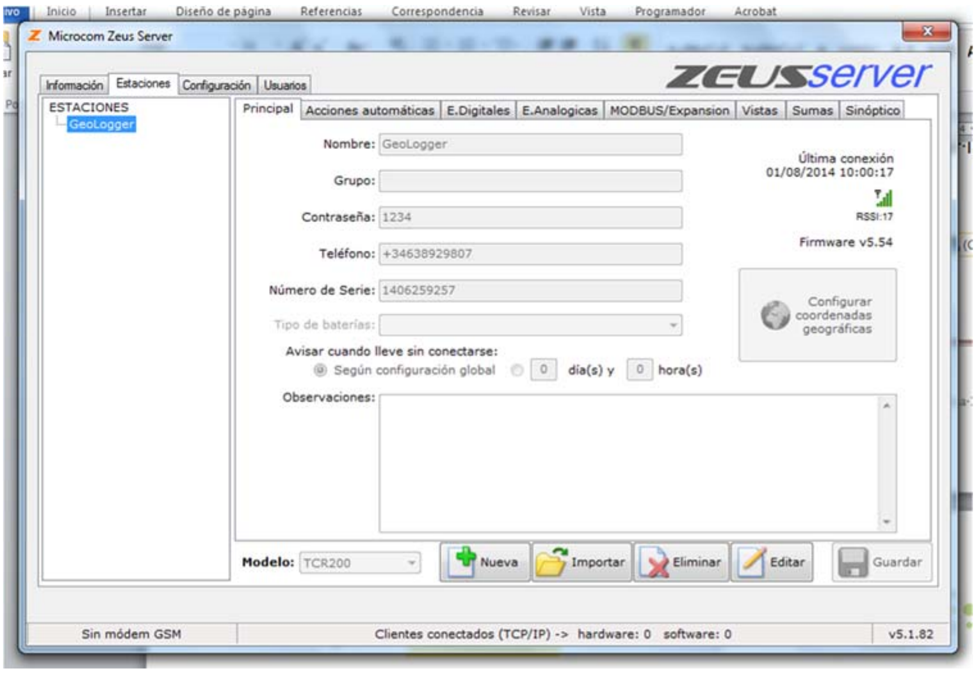
- Configuration of the Modbus registrations to consult of the network analyser and of the activation detector. The following registrations are chosen: average voltage of the three voltage probes, individual intensity of the three voltage probes, total active power, total reactive power, accumulated power, state of activation, flag of activation change.

- Configuration of the periodic storage every 5 minutes of the first 8 registrations indicated in the previous point.

- Configuration of the storage by change of the activation flag of the same registrations indicated in the previous point. The datalogger is configured in such a way that this storage gets done once per minute as maximum.

- Configuration of the downloading of the data to the server every 15 minutes.

After these steps are completed, the equipment is ready to collect all consumption parameters, but it's still necessary to have a server able to store the data and provide them in a comfortable way to the final user.



In the case of not having access to a server to download periodically all the data, the memory of the datalogger would be completely filled in approximately 3 days and the previous data would definitively be lost.

Due to the fact that the datalogger from Microcom doesn't use methods of dynamic giving names of domains (for example Dyndns) it is required to install the server software in a PC with fixed IP, for which the steps are:

- Install the server software (delivered with the datalogger) in a PC from the Installations Department Headquarters of GEOCONTROL in Madrid.

- The server software is configured to work in the port 11111 and to recognise the datalogger of the manufactured equipment.

- Configure the PC server with a fixed address within the internal network of GEOCONTROL.

- Configure the NAT of the router of GEOCONTROL to deviate the port 11111 of the public fixed address 195.57.183.98 to the port 11111 of the local IP address of the PC server.

Once the supervisor equipment and the server configured, the tests over both of them can get started.

8. TESTS OF THE SUPERVISOR EQUIPMENT OF CONSUMPTION V1

Statens vegvesen
Vegdirektoratet
Publikasjonsekspedisjonen
Postboks 8142 Dep 0033 OSLO
Tlf: (+47 915) 02030
publvd@vegvesen.no

ISSN: 1893-1162

vegvesen.no

Trygt fram sammen