TUESDAY 3 AUGUST 2004 AM

Earth Based Instrumentation

Conveners: G. Jentzsch and O. Francis

PRESIDING

G. Jentzsch, *Institute of Geosciences, University of Jena, Jena, Germany*
O. Francis, *University of Luxembourg and European Center for Geodynamics and Seismology*

Paper No	Time	Type	Title	Authors
ETS-01-01	08:30-09:00	I/O	Superconducting Gravimeters: Current Production Models and Future Development.	E. Brinton, R. Warburton
ETS-01-02	09:00-09:15	C/O	A New Data Series Observed with the Remote Gravimeter GWR C038 at the Geodetic Fundamental Station TIGO in Concepción (Chile)	H. Wilmes, A. Boer, B. Richter, P. Wolf, M. Harnisch, G. Harnisch, H. Hase
ETS-01-03	09:15-09:30	C/O	Validation of the Frankfurt Calibration System for Superconducting Gravimeters	B. Richter, I. Nowak, H. Wilmes, R. Falk, M. Harnisch, G. Harnisch
ETS-01-04	09:30-09:45	C/O	Some Recent Results of the Gravimetric Tidal Station Pecny, Czech Republic	V. Palinkas
ETS-01-05	11:30-11:45	C/O	The very-broad-band digital data acquisition of the long-base tiltmeters of Grotta Gigante (Trieste, Italy)	C. Braitenberg, G. Romeo, Q. Taccetti, I. Nagy
	10:00-11:00	**COFFEE BREAK and POSTER VIEWING**		
ETS-01-06	11:00-11:30	I/O	A 100m Laser Strainmeter System in Kamioka, Japan, for precise observations of Tidal Strains	S. Takemoto, A. Araya, W. Morii, J. Akamatsu, M. Ohashi, H. Momose, A. Takamori, S. Miyoki, T. Uchiyama, D. Tatsumi, T. Higashi, Y. Fukuda
ETS-01-07	11:30:12:00	I/O	Results of the International Comparison of Absolute Gravimeters in Walferdange (Luxembourg) of November 2003	O. Francis
	12:00	**END OF SESSION**		
	12:00-13:30	**LUNCH BREAK**		
POSTERS				
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ETS-01-09		C/P	Tidal gravity observations in eastern Siberia at Khabarovsk/Zabaikalskoe and along the atlantic coast of France at Chize	V.Yu. Timofeev, M. van Ruymbeke, G. Woppelmans, M. Everaerts, E.A. Zapreeva, P. Yu. Gornov, B. Ducarme
ETS-01-10		C/P	Vertical and horizontal seismometric observations of tides	S. Lambotte, L. Rivera, J. Hinderer
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ETS-01-12		C/P	A new design of the long water tube tilt meter of FGI	H. Ruotsalainen
ETS-01-13		C/P	On modern development of strainmeters and tiltmeters in Russia	I.Vasiliev, L. Latynina, G. Jentzsch
ETS-01-14		C/P	Tidal water level changes in deep wells: implications on the determination of the elastic parameters of the aquifer	V.Yu. Timofeev, B. Ducarme, E. Zapreeva, G.N. Kopylova, P.Yu. Gornov, L. Vandercoilden, S.V. Boldina
ETS-01-15		C/P	Calibration and reference level stability of the Canadian Superconducting Gravimeter Installation	J.B. Merriam, J. Liard, S. Pagiatakis

C: ***Contributed*****; I:** ***Invited*****; O:** ***Oral*****; P:** ***Poster***

ETS-01-01

Superconducting Gravimeters: Current Production Models and Future Development.

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Continued development of the Superconducting Gravimeter (SG) has resulted in an instrument, which can yield higher quality data and is easier to deploy and operate. Many of the improvements relate to support systems including the integration of a low power 4 Kelvin refrigerator and ultra-efficient Dewar. With this system there is no need to transfer liquid helium during normal operation, thereby eliminating this source of disturbance. The Dewar has been reduced in size from 125 liters to 35 liters while maintaining adequate thermal ballast for refrigeration failures of more than three weeks. The control electronics and data logging system can now be monitored and manipulated via a TCP/IP connection making remote, unattended operation practical. With these improvements the SG can be easily transported and operated with minimal infrastructure and training. The instrument can now be used for a wider range of applications such as, Hydrology, Volcanology, and Reservoir Monitoring, which will benefit from ultra-stable continuous gravity measurements.

In addition, we examine the tradeoffs associated with constructing smaller SGs. Ease of deployment, maintaining sufficient thermal ballast to acquire long un-interrupted data sets, power consumption and the ability to utilize small inexpensive vaults are considered. In particular, we look at a concept design for operating an array of small SGs without ever needing to handle liquid helium. This system would be ideal for remote gravity or long period seismic terrestrial and seafloor measurements.

ETS-01-02

A New Data Series Observed with the Remote Gravimeter GWR C038 at the Geodetic Fundamental Station TIGO in Concepción (Chile)

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Since November 2002 the Transportable Geodetic Observatory TIGO near Concepción (Chile) is equipped with the superconducting gravimeter GWR C038, installed in a separate gravimeter building. This is the first installation of a superconducting gravimeter in South America and the first prototype of a GWR remote gravimeter in practical operation. The gravimeter uses the latest technical developments to facilitate the instrument operation and data transfer with remote control capabilities.

Several details of the gravimeter, especially the construction of the Dewar and the cooling system are optimized to achieve a simplified technical handling. Remote techniques make it possible that the gravimeter can be monitored and controlled from a distant location. The GWR data acquisition system records not only digitally filtered data from the gravity sensor but also several instrumental and environmental data. All data are transferred on an hourly basis to the BKG central facilities in Frankfurt M., Germany. Here, the data are preprocessed and the residual curves are checked and compared to the three other monitored gravimeters of the BKG to verify a proper system operation. The experiences during the first 18 months of operation at the TIGO station Concepción and first results will be discussed.

ETS-01-03

Validation of the Frankfurt Calibration System for Superconducting Gravimeters

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Superconducting gravimeters provide observations with high resolution and low drift rates but are still relative. In the beginning the superconducting gravimeters were calibrated indirectly by comparisons with other relative gravimeters calibrated on calibration lines or by other means. In the last decade methods for absolute calibration of superconducting gravimeters have been developed. At BKG two different procedures are applied, the comparison with parallel absolute gravity measurements and the calibration by small sinusoidal accelerations of the gravimeter. For the latter purpose the "Frankfurt Calibration System" has been produced and tested in several applications.

All absolute gravity measurements performed at BKG SG stations in times of high tidal gravity variations are evaluated to determine the scale factor of the superconducting gravimeters. Under optimal conditions an accuracy of the order of 1 nm s-2/V can be achieved. However, a reliable estimation of the phase shift caused by the gravimeter system response is not possible.

Using the artificial acceleration calibration method the scale factors can be determined by one order of magnitude more accurate and in addition the instrumental phase shift is estimated with an accuracy of the order of 1 second. In the case of dual sphere superconducting gravimeters, the independent results for both systems may be compared very accurately by means of the difference signal.

The weakness of the acceleration calibration is the extrapolation of the calibration factor from short periods (300 1200 s) to the tidal frequencies. Hence the used transfer function model is validated by two independent methods which compliment the acceleration method. In one case a sinusoidal signal is superimposed to the gravity signal in the other a "classical" step function is applied. The results of the different calibration methods will be presented and discussed.

ETS-01-04

Some Recent Results of the Gravimetric Tidal Station Pecny, Czech Republic

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The tidal measurements at the Geodetic Observatory Pecny began in 1970. New gravity tide records have been made by the LCR G No.137 (LCR 137) equipped by the MVR feedback and by the Askania Gs 15 No. 228 (ASK 228) equipped with an electromagnetic feedback in the reconstructed tidal laboratory Pecny since August 2002. The standard deviation of the weight unit was 0.065 microgal and 0.20 microgal, respectively.

The air temperature and relative humidity are stabilized within the range of 0.2 ^{o}C and 3%, respectively, during a year. The significant linear correlation between the gravimeter drift of the LCR 137 and the humidity was found from experimental investigations of the temperature and humidity effects on this instrument.

The repeated absolute gravity measurements with the FG5 No. 215 at the observatory Pecny were used for computing and checking calibration coefficients of the tidal gravimeters ASK 228 and LCR 137. From four-day simultaneous measurements during tidal variations of about 240 microgal the calibration coefficients were determined with a precision of 0.05%. The scales of the tidal gravimeters were determined from 25 absolute campaigns with the accuracy of 0.04%.

ETS-01-05

The very-broad-band digital data acquisition of the long-base tiltmeters of Grotta Gigante (Trieste, Italy)

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The horizontal pendulums of the Grotta Gigante (Giant Cave) in the Trieste Karst, are long-base tiltmeters with Zöllner type suspension. The instruments have been continuously recording tilt and shear in the Grotta Gigante since the date of their installation by Prof. Antonio Marussi in 1966. Their setup has been completely overhauled several times since installation, restricting the interruptions of the measurements though to a minimum. The continuous recordings, apart from some interruptions, cover thus almost 40 years of measurements, producing a very noticeable long term tiltmeter record of crustal deformation. The original recording system, still in function, was photographic with a mechanical timing and paper-advancing system, which has never given any problems at all, as it is very stable and not vulnerable by external factors as high humidity, problems in power supply, lightning or similar. In December 2003 a new digital recording system was installed, based on a solid-state acquisition system intercepting a laser light reflected from a mirror mounted on the horizontal pendulum beam. The acquisition frequency is 30 Hz, which turns the long-base instrument to a very-broad-band tiltmeter, apt to record the tilt signal on a broad band of frequencies, ranging from secular deformation rate through the earth tides to seismic waves. Here we describe the acquisition system, present the up to date long term recording, and the observation of a recent earthquake.

ETS-01-06

A 100m Laser Strainmeter System in Kamioka, Japan, for precise observations of Tidal Strains

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A 100m laser strainmeter system was installed in a deep tunnel about 1,000m below the ground surface at Kamioka, Gifu, Japan. The system consists of three types of independent interferometers: (1) an EW linear strainmeter of the Michelson type with unequal arms, (2) an NS-EW differential strainmeter of the Michelson type with equal arms and (3) a NS absolute strainmeter of the Fabry-Perot type. These are configured in L-shaped vacuum pipes, each of which has a length of 100m. (1) and (2) are highly sensitive (order of 10-13 strain) and have wide dynamical range (10-13 - 10-6). Observations with strainmeters (1) and (2) started on June 11, 2003. (3) is a new device for absolute-length measurements of the order of 10-9 of a long-baseline (100m) Fabry-Perot cavity by the use of phase-modulated light. This third strainmeter will be ready for operation before the end of 2004.

Based on data of 5 months from June 12, 2004, “observed” tidal strain amplitudes of 8 major constituents were compared with “theoretically expected” ones that were obtained from the GOTIC2 program (Matsumoto et al., 2001). As a result it was revealed that the “observed” amplitudes are about 10% smaller than the “expected” amplitudes. This discrepancy can be explained by the topographic effects around the observation site.

ETS-01-07

Results of the International Comparison of Absolute Gravimeters in Walferdange (Luxembourg) of November 2003

O. Francis
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On November 3rd to November 7th 2003, Luxembourg's European Center for Geodynamics and Seismology (ECGS) hosted an international comparison of Absolute gravimeters in their Underground Laboratory for Geodynamics in Walferdange (WULG). This is the first time in the history of geophysics that 15 absolute gravimeters will have been brought together in the same location for simultaneous observations. Teams from all over the world including the United States and Brazil as well as teams from Europe participated in the intercomparison.
The WULG is environmentally stable (i.e. constant temperature and humidity within the lab), and is extremely well isolated from anthropogenic noise. Data analysis as well as a discussion on the results will be presented. Overall, the absolute meters agreed with a standard deviation of less than two microgal (if we exclude one prototype instrument from the analysis). For the first time, the ability of the operators was put to the test. The experiment indicates that the errors due to the operator is less than 1 microgal, i.e. within the observation error bar and is in fact lower than the accuracy of the absolute gravimeters.
This historic experiment marks the recognition of the WULG as an international absolute gravimeter intercomparison site. It is expected, that these intercomparisons will occur every two years.

ETS-01-08

The Automated Burries Gravity Meter - a New Instrument for Surveying and Continuous Operation

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The Automated Burris Gravity Meter™ is a new development on the basis of an old and well-known system: the zero-length spring. It was designed to eliminate the need to purchase separate meters for different applications. The UltraGrav™ control system allows the user to choose the level of accuracy needed for each application. Lower accuracy results in faster reading times, allowing more stations to be logged in a day. Higher accuracy allows the gravimeter to be used for the most demanding microgal surveys. Thus, the Burris Gravity Meter™ can be configured for all specific application needs, in geophysical and geotechnical exploration, civil engineering and regional geological mapping, groundwater and environmental studies, as well as tectonic and volcanologic research

Each Burris Gravity Meter, produced by ZLS Corporation, is built around a handcrafted, metal, new zero-length spring. ZLS springs have extremely low hysteresis and drift rates. When new, ZLS springs typically have drifts of 1.0 to 2.0 mGals per month, decreasing to typically less than 0.5 mGal per month. The prototype has a drift rate of approximately 0.030 mGal per month. The dial is calibrated every 200 mGals over the entire 7,000-mGal meter range. Calibration values are stable over time as they are determined by a hardened micrometer screw. The standard Burris Gravity Meter has consistently yielded standard deviations of 0.003 mGal or better during routine field tests. The export version has a resolution of 10 microgals.

The gravimeter is operated fully digital and has a microprocessor-based automatic reading and data logging system. The UltraGrav control system incorporates an inherently linear pulse-width modulated (PWM) electrostatic feedback system to automatically null the beam (range ± 25 mGal). It takes the reading, applies the calibration factor, and optionally, corrects for earth tides and level position, then stores the data and displays the results. Data are protected in Flash RAM in the event of power loss. This system comes installed on a palmtop computer for flexibility in the field. For continuous operation a PC-version is available for a separate computer with a DOS-operating system.

In co-operation of the universities of Jena and Moscow an Earth tide recording station was developed, basing on the Burries gravimeter with the option of the stepping motor dial control. The additional DOS-computer (Panel-PC MediaLine S12-NG) is connected to a notebook computer (IBM Thinkpad T30) for data acquisition and communication. The recording program was developed from a former version, allowing parallel recording of air pressure and GPS-time. The data are sampled every second, transferred to the notebook and filtered to 10-second samples which are stored in daily files together with air pressure. The recording program is interactive, offering an inspection of the direct data prior to filtering as well as plots of the past 6, 12, 24, 48 hours and the last week, both gravity data and air pressure. We use a Vaisala PTB210 digital barometer with a resolution of better than 1 hPa.

If strong drifts are to be expected one can choose the option of allowing to set the dial automatically in order to avoid the data to go off the feedback range.

In the poster we will present the Automated Burris Gravity Meter™ with its UltraGrav™ control system and describe the Earth tide recording station developed at the Institute for Geosciences, University of Jena. We will present some results.

ETS-01-09

Tidal gravity observations in eastern Siberia at Khabarovsk/Zabaikalskoe and along the atlantic coast of France at Chize

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Tidal gravity observations have been performed during more than 2 years (April 2001 - September 2003) in Eastern Siberia with the LCR402. Simultaneously the gravimeter LCR1006 was recording in Chizé Observatory, in the region of La Rochelle, Atlantic coast of France. Both stations are located far enough from the sea to avoid very local effects in ocean tides loading. In both stations the room temperature showed annual variations and in Khabarovsk, power interruptions during winter time produced rapid temperature changes in the recording room. Instrumental failures occurred too. It is a reason why the internal errors on the tidal parameters are still rather large: 0.3% on M2 at Khabarovsk and 0.15% in Chizé. The main goal of the project was to compare the observed tidal parameters with the ocean tides effects, using different oceanic models i.e.: SCW80, CSR3, FES95, ORI96, CSR4, FES99, FES02, GOT00 and NAO99.

A general conclusion is that the predictions using all the oceanic models, except FES99 on M2, are in agreement within 0.2% for the area of Khabarovsk (Eastern Siberia). The dispersion is slightly reduced for the more recent models. We may thus consider that a mean of all the oceanic models will have a precision better than 0.1%. It would thus be very difficult to improve the models using tidal gravity observations in this area.

For Chizé however the different oceanic models disagree at the level of 0.5% and the observations may provide useful constrains. Moreover the M4 wave has an amplitude factor larger than 10 and a phase difference close to 180°. It could be due to the shallow water component M4 existing along the coast and in the estuary of the river Gironde.

ETS-01-10

Vertical and horizontal seismometric observations of tides

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It is known that it is possible to retrieve reasonably good tidal signals (diurnal and semidiurnal) from digital records of the output of modern long-period seismometers. This is especially true when the instruments are properly installed, on stable material, and isolated from environmental perturbations. The vertical component is usually less noisy than the horizontal ones and the tidal signals predicted by the theory of an elastic Earth model with an oceanic load are in very good agreement with the corresponding observations. On the contrary, the horizontal terms exhibit strong discrepancies with respect to theoretical predictions. The well-known explanation for this disagreement lies in the local effects such as topography, local geology and particularly the cavity effect when the sensor is installed inside a vault. We treat here long series (~1 month) of data from several permanent broad-band seismological stations. Vertical seismometric records are shown to accurately reproduce either the measurements of nearby gravimeters in the tidal and subtidal frequency bands (T < 24 h) or the theoretical predictions, especially when pressure data are available and included in the analysis. We also treat records from horizontal seismometers in order to examine the contribution of the different geophysical observables: tilts, horizontal and vertical displacements, strains, gravity. Special attention is devoted to the problem of finding a minimal set of observables necessary to predict the seismological records, to the inverse problem of recovering the observables from a set of records and to the stability in the long term (years) of the result of such analysis.

ETS-01-11

The “wth2o” water-tube tiltmeter.

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We present in this poster a new prototype of long base water-tube tiltmeter named “wth2o”. This system, particularly simple by the absence of moving parts, showed a great reliability and a fairly high stability (linear drift rate of 5 10-9 rad/month). Its high resolution up to the long-period seismic band (where for instance the resolution is better than 0.001 masec, or 5 10-12 rad) and its very low noise level enabled us to obtain Earth tide observations in excellent accordance with the models, with the lowest root mean squares among all the results obtained with other tiltmeters in Walferdange. With this instrument we have also observed some events rarely measured with a water-tube, such as the gravest toroidal and spheroidal

modes of the Earth free oscillations excited by the Mw 7.9 Denali earthquake or the successive passages of Love waves (up to G7) circling 3 times the globe after that quake. Theoretical models of this instrument (taking into account the damping produced by the liquid's flow between the plates of the capacitive sensors) allowed to obtain the solutions of the equations of motion for tilt as well as for horizontal displacement. From these solutions we were able to produce accurate theoretical transfer functions, as confirmed by the successful comparison with observed frequency responses.

ETS-01-12

A new design of the long water tube tilt meter of FGI

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A new model of the long water tube tilt meter has been designed and built in the Finnish Geodetic Institute. By improving thermal and mechanical long term stability and interferometrical water level sensing, we may observe more reliably amplitudes and phases of some small diurnal waves of tidal tilt and related resonance waves.

ETS-01-13

On modern development of strainmeters and tiltmeters in Russia

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(2) Institute of Geosciences, University of Jena, Germany

In the Institute of Physics of the Earth of the Academy of Sciences, Russia, new designs of strainmeters and tiltmeters were developed, intended to equip geophysical observatories. In this paper the features of their design are described, and the results of operational tests are given. These instruments are assigned to measure rock deformation and tilt in order to study present movements of the Earth's crust, Earth tides, long-period seismic oscillations and also to carry out the monitoring of ecologically hazardous industrial objects.

The rod strainmeter, one to 30 meters long is being assembled of quarts tubes of 30-50 mm diameter when being mounted in an underground chamber. One end of the rod is rigidly fastened to rock. The displacement of the second free end relative to the rock is monitored using a capacitive transducer, to be recorded with different systems. The capacitive transducer is a precise mechanical device which ensures stability of the operation, relative simplicity of its installation, and regulation of differential capacitive transducers during the observations. Also the calibration is described. Technical parameters of the strainmeter and the methods of their stability control are given.

The strainmeters of a given construction underwent long standing tests at geophysical stations. The most important evaluations in practice of strain measurements are the following: the calibration error is less than 2-3%, long period stability of the instrument derived from data of parallel instruments is better than $5*10^{-7}$ per year. An example of two parallel records over several months will be given.
The tiltmeter with a capacitive displacement transducer assigned to measure tilts of the Earth's surface in two directions is being described. The tiltmeter consists of a sensor, electronics, control unit and recording equipment. The sensor is constructed as a vertical pendulum type with two-coordinated capacitive converters.

The technical parameters of the tiltmeter are given and the construction of the sensor is demonstrated. The instrument has a high sensitivity to tilts ($1*10^{-4}$ arc sec). The reliability of the measurements is high, due to mechanical construction and modern technology. The error of the tilts read-out does not exceed 2%, and the instrumental "zero" drift does not exceed ± 1 arc sec a year. The electronics of the tiltmeter is identical to the strainmeter. The tiltmeters are calibrated at a special test platform, and it is sufficient to repeat such tests no more than once a year. During the recording of the tiltmeter the stability of the tilt signal may be also controlled by the calibrated electrostatic effect on the sensor. The results of the parallel record of tilts by a group of tiltmeters demonstrate quality of the tilt observations, which will be given in the paper. Strain measurements are accompanied by measurements of the temperature and pressure variations in the underground chamber, using thermometers with a sensitivity of 0.001 K and a barometer with the sensitivity of 0.003 hPa.

ETS-01-14

Tidal water level changes in deep wells: implications on the determination of the elastic parameters of the aquifer

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Water level fluctuations in wells reflect tide, barometric, and tectonic effects. Atmospheric pressure and water level are monitored in deep wells located in Far East Russia: a continental point 300 km far from the Pacific Ocean -Bychikha well, Khabarovsk region and a point 15 km far from coast UZ5 well, Avacha bight, Kamchatka peninsula. The data were used to study the response of the well-aquifer system to periodic tidal loading and atmospheric pressure changes. Water level fluctuations record pressure head disturbances caused by dilatation of the aquifer as well as atmospheric pressure variations and it is thus possible to obtain the elastic constants and porosity of the aquifer using a static model analysis. The experiments confirmed the possibility to monitor these parameters to an accuracy of 1%.

ETS-01-15

Calibration and reference level stability of the Canadian Superconducting Gravimeter Installation

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The Canadian Superconducting Gravimeter Installation and the Canadian Absolute Gravity Site are co-located in Cantley, Quebec. Since 1998 joint observing sessions ranging from a few days to more than a week in duration have been conducted periodically to monitor the reference level and calibration of the superconducting gravimeter and to investigate short term excursions in the joint record. Fourteen trials, between March 1998 and July 2003, have yielded a calibration constant of -78.34+/-0.15 microgal/V. This is in agreement with the original calibration supplied to GGP. A comparison of monthly estimates of the principal tides shows that the relative calibration has changed much less than this. The reference level

(corrected for subjectively defined tares) has remained within +/-8 microgal of the mean level. The long term drift appears to be less than a microgal per year, but short term excursions in reference level of several microgal in a few months are common. The origin of these excursions is unknown, but it is unlikely that they represent the accumulation of uncorrected tares.