

# Design and Performance of the new Sartorius Robot-System

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## Abstract

The Sartorius Robot System CCR10-1000 is designed for fully automatic mass determination in a mass range from 1kg down to 1mg. The Robot System includes two Mass Comparators each equipped with a magazine for storage of weights. The portal robot system is a 3-axis system with an additional axis of rotation where a unique weight handler system is installed.

The control unit running the control software allows flexible and easy programming of the required measuring sequences. Routine mass calibrations as well as sophisticated weighing series can be performed.

A detailed description of the technical and metrological parameters as well as measurement results will be presented.

*Keywords:* Robot-System; E1-MassScale; Mass Comparator

## 1. Introduction

The development of the automatic robot system is based on a collaboration between the Technical University of Ilmenau/Germany (TUI) and Sartorius AG/Germany. Due to former common developments in the field of mass metrology Sartorius decided to fix further activities in the matter of an automatic robot system with the Institute of Process- Measuring and Sensor Technology at TUI. The robot system itself was designed by a German company called Anfotec®, a well experienced manufacturer of fast speed robot systems for high accuracy positioning. Together with the core competence of Sartorius in the field of high accuracy mass determination two commercial mass comparators have been modified for the special application of covering the whole mass range from 1kg down to 1mg. This accumulation of competence leads to a successful development of this unique robot system. The idea was to offer an automatic system which will be able to perform the dissemination of the mass scale without any manual intervention as well as the fast speed calibration of weights or weight sets.

The new Robot System CCR10-1000 is build for use in the following applications:

Dissemination of the mass scale of NMIs in the range from 1 kg to 1mg

Calibration of weights and weight sets by comparative weighing of the test weight against a reference weight

Calibration of weight samples against a reference weight

Calibration of weights with different design and shape like OIML-Class weights [1]

as well as ASTM weights.

## 2. Modules and Set-up

In the following the modules of the Robot System and possible versions for a set-up are described.

The CCR10-1000 Robot-System consists of the main parts:

- The gantry Robot-System with control unit
- The robot gripping device
- Magazines and storage for reference weights
- The build in Mass Comparators,
- The housing and balance support table

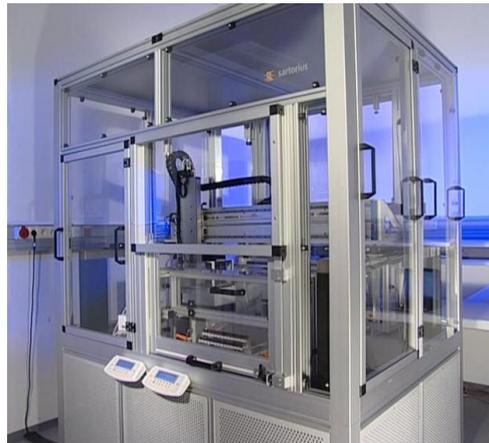


Fig. 1. Complete Robot System with Housing

### 2. 1 The portal robot system

The design of the robot system was developed due to the multi-functional applications of the CCR10-1000. We need at least 3-axes to handle the weights in the magazine and transfer them to the respective mass comparator. According to the high accuracy mass determinations of OIML-class E1 weights all main axes have to be stable and solid to guarantee reproducible readings from the mass comparators. Also the positioning of the gripper into magazine places and into weighing pan needs stable and reproducible movements of the robot system. The dimension of the portal system finally depends on the space for the magazines and the two mass comparators. These requirements lead to the following design of the portal system, shown in Figure 2.

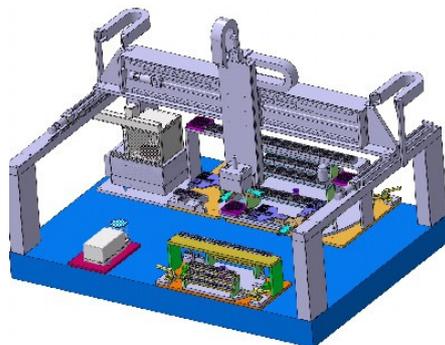


Fig. 2. Design of the portal robot system

The basic dimensions are: 1350 x 1700mm. The base plate is made of artificial stone with a thickness of 100mm. The base plate carries the robot system and the magazines for both mass comparators. For best insensitiveness of the mass comparators during movement of the robot system, each carrier for the mass comparators is separated from the base plate by 4 vertical brackets. These strut on the mass comparator weighing table below the base plate.

## 2.2 *The robot gripping device*

The patented 4-gripper system (Figure 3) was developed for easy and fast loading of the build in mass comparators. Therefore the vertical axis of the portal robot system is equipped with an axis of rotation on which two grippers for each mass comparator are fixed. The grippers are located under an angel of 90 degrees. To load the weights from magazine or to the weighing pan, the gripping device has to be turned only these 90 degrees to fulfil complete mass determination on each mass comparator. Each pair of grippers consists of a single-gripper and a multi-gripper. The multi-gripper (Figure 4) is designed to take maximum 4 weights as a sample, the single gripper takes the reference weight to be compared with. The special grippers are designed to take any possible weight shape used for OIML-class weights. After collecting different weights from the magazine to a special sample magazine place, the multi-gripper can take the sample and is ready for the measurement process.

To fulfil the complete mass dissemination as described above the gripper for the 10g-mass comparator needs to transfer the 10g weight from the 1kg mass comparator. This is realized by a special magazine place which fits for both designed different divisions of the grippers fin.



Figure 3. Gripper system in front of the sample of 1kg-magazine 1kg-mass



Figure 4. Multi-gripper with sample of weights for the comparator

### 2.3 The magazine

There exist two independent magazines, for each mass comparator one. The 1kg magazine (Figure 5) makes available 23 places for weights from 1kg down to 10g. Two additional magazine places are provided to take disk weights up to a diameter of 100mm. Each magazine place is marked for easy loading the weights into centre. The magazine for the 10g mass comparator (Figure 6) provides 35 places for OIML-shape weights like cylindrical or knob-weights as well as for wire and flat weights in the range from 1mg to 500mg.

For the reference weights a special magazine is build in for each mass comparator which is accessible through a second door.



Figure 5. 1 kg-magazine



Figure 6. 10 g-magazine

#### 2.4 The build-in mass comparators

The 1kg mass comparator (Figure 7) is modified from the Sartorius CC1000S-L weighing cell with additional automated internal substitution weights. This allows to cover the whole range from 1kg down to 10g on this unit. The 1kg Mass comparator is equipped with a special spring based Centermatic pan. This pan centres the weight or the sample of weights into the centre of gravity of the mass comparators weighing axis to prevent any eccentric load error.

The centring procedure is part of the control software and can easily be changed on the software control panel. A default value for the number of centring procedures is given in the software depending on the desired accuracy class of mass determination.

To fulfil the requirements of a full mass dissemination from 1kg down to 10g a special weight substitution system was developed and installed into the housing of the weighing system. Three additional weights in connection with the 4 build in substitution weights cover the necessary mass range according to the OIML weight scheme.

For the required specifications for mass dissemination as described in section 4 we need the above described mass comparator for 1kg maximum load with a readability of  $1\mu\text{g}$  and another mass comparator for 10g maximum load with a readability of  $0,1\mu\text{g}$ . For this application an ultra-microbalance had to be modified to be used as a triple range mass comparator. With the two internal substitution weights of 3.5g and an additional electronic weighing range of 3.5g the maximum weighing range of 10g can be covered. Both mass comparators are equipped with automatic doors to open the weighing room. The doors movement is controlled by the robot system application software.



Figure 7. 1kg-mass comparator

### 3. The control unit with application software

The control unit consists of 2 main parts, which are installed in the bottom of the of the robot system housing. These are the controller for the driver motors for all necessary movements of the portal robot system and a PC for the operating software.

The operating software of the robot system consists of software for controlling the desired mass comparison sequences and of evaluation software for calculating the measurement results using all the features necessary for this. The structure of the evaluation software is essentially comprised of the following modules:

- Determination of the conventional mass by substitution weighing
- Highly accurate mass determination by substitution weighing
- Dissemination of the mass scale
- Recording the climate data synchronously to all balance readings and calculate the air density using the CIPM formula

### 4. Specifications

The CCR10-1000 robot system is equipped with 2 separate magazines for the build-in mass comparators. The robot system offers a fully automatic loading of the mass comparators providing a 3-axis portal system with additional swivel axis to rotate the grippers. The maximum diameter of weights is 55 mm for cylindrical and for spherical objects on the 1kg-magazine and 16 mm diameter for wire weights and leaf weights on each magazine position on the 10 g magazine.

In addition it is possible to position cylindrical objects with a maximum diameter of 100 mm on 2 special magazine places on the 1kg magazine.

The maximum height of the weights is 90 mm on the 1kg magazine and 20mm on the 10g magazine (also in the form of stacked disc weights).

The specifications are as follows:

The maximum capacity of the build-in mass comparators is 1002 g.

The use of internal substitution weights enables the mass of any values to be determined in a range from 1 mg up to the mass comparator's maximum capacity of 1000 g.

1kg-mass comparator:

- The maximum load for nominal mass is 1002 g.
- The electrical weighing range is 2 g.
- The readability is 1 µg.
- The repeatability is ≤ 3 µg (10g...100g) and ≤ 8 µg (200g...1kg).
- The linearity in the electrical weighing range of 500mg is ≤ 15 µg.
- The stabilization time is ≤ 30 s.
- The sensitivity drift is ≤ 1 ppm/°C.

10g-mass comparator:

- The maximum load for nominal mass is 10 g.
- The electrical weighing range is 3.5 g.
- The readability is 0.1 µg.
- The repeatability is ≤ 0.3 µg.
- The linearity in the electrical weighing range is ≤ 1 µg.
- The stabilization time is ≤ 30 s.
- The sensitivity drift is ≤ 1 ppm/°C.

## 5. Results

Measuring results of 1 vs. 1 mass comparison at the maximum capacity of each mass comparator are presented:

### 5.1. 1kg mass comparator

Two 1kg stainless steel E2 grade knob shaped weights have been compared with the following results:

Mass comparison between position A = Pos A1 and B = Pos B1. 6 ABBA cycles											
		A	Std.Dev.	B	Std.Dev.	B	Std.Dev.	A	Std.Dev.	2nd Diff.	T1
		in mg	in µg	in mg	in °C						
12-09-2007	18:07:22	-7.96096	( 0.73)	-7.59177	( 0.43)	-7.60676	( 0.44)	-7.97264	( 0.49)	0.36754	21.52
12-09-2007	18:14:25	-7.99200	( 0.69)	-7.61488	( 0.53)	-7.61635	( 0.49)	-7.98572	( 0.46)	0.37325	21.49
12-09-2007	18:21:27	-7.99032	( 0.63)	-7.61300	( 0.00)	-7.61156	( 0.51)	-7.97744	( 0.51)	0.37160	21.47
12-09-2007	18:28:30	-7.98077	( 0.43)	-7.60016	( 0.37)	-7.60412	( 0.67)	-7.97081	( 0.49)	0.37365	21.45
12-09-2007	18:35:33	-7.97668	( 0.48)	-7.59664	( 0.49)	-7.59300	( 0.00)	-7.96076	( 0.44)	0.37390	21.47
12-09-2007	18:42:36	-7.96200	( 0.00)	-7.58600	( 0.00)	-7.58680	( 0.41)	-7.95932	( 0.48)	0.37426	21.46
Result:									Mean =	0.37237 mg	
									Std.Dev. =	2.54 µg	

Figure 8. Results of a comparison of two 1 kg cylindrical stainless steel weights

### 5.2. 10 g mass comparator

Two 10 g stainless steel E2 grade knob shaped weights have been compared with the following results:

Mass comparison between position A = Pos G1 and B = Pos G11. 6 ABBA cycles										
	A	Std.Dev.	B	Std.Dev.	B	Std.Dev.	A	Std.Dev.	2nd Diff.	T1
	in mg	in µg	in mg	in °C						
10-09-2007 15:57:10	2826.24696 ( 0.26)		2826.25047 ( 0.21)		2826.25216 ( 0.25)		2826.25265 ( 0.22)		0.00151	22.02
10-09-2007 16:02:21	2826.25355 ( 0.21)		2826.25598 ( 0.22)		2826.25664 ( 0.22)		2826.25690 ( 0.37)		0.00108	22.02
10-09-2007 16:07:31	2826.25769 ( 0.21)		2826.25971 ( 0.25)		2826.26012 ( 0.26)		2826.26003 ( 0.21)		0.00106	22.02
10-09-2007 16:12:42	2826.25996 ( 0.25)		2826.26238 ( 0.21)		2826.26282 ( 0.23)		2826.26208 ( 0.20)		0.00158	22.02
10-09-2007 16:17:52	2826.26252 ( 0.20)		2826.26442 ( 0.25)		2826.26482 ( 0.23)		2826.26374 ( 0.22)		0.00149	22.02
10-09-2007 16:23:03	2826.26381 ( 0.23)		2826.26568 ( 0.24)		2826.26608 ( 0.20)		2826.26518 ( 0.20)		0.00138	22.03
Result:									Mean =	0.00135 mg
									Std.Dev. =	0.23 µg

Figure 9. Results of a comparison of two 10g cylindrical stainless steel weights

## 6. Conclusion

The new Sartorius CCR10-1000 Robot system is designed to fulfil high accuracy mass determination in OIML Class E1 as well as for fast speed calibrations with lower OIML-accuracy class weights.

For each Mass Comparator a special rotating double magazine is designed to carry complete weight sets. During mass determination the outer magazine can be unloaded and loaded without interruption of the mass determination procedure inside the enclosure.

The weight handler system consists of 2 special weight holders for each Mass Comparator. One of each couple of weight holders is designed to take a sample of up to 4 weights. The weight sample will be fully automatically combined of single weights from the magazine, depending of the chosen mass determination. The sample weights are loaded on a special pan at the magazine by the single weight holder, before they are taken all together by the second so called multi weight holder.

During mass determination the rotating axis just turns in front of the Mass Comparators weighing chamber to change the weights. The test weight, or sample, remains on the gripper during measurement of the reference weight and the opposite way which allows quick and easy mass determination procedure. Due to the special construction of the robot system mass determination can take place at both Mass Comparators simultaneously. This time saving procedure allows efficient calibration of different weight sets in the whole weighing range.

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## References

- [1] International Recommendation OIML R 111, Part 1: Metrological and Technical Requirements