

측정 프로세스 능력 평가 절차 ISO 22514-7, MSA 4, VDA 5 비교연구

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초록

- 측정은 공정관리, 품질관리에서 매우 중요한 역할을 하고 있다. 제조현장에서 정확하지 못한 측정값은 제품의 품질 판정에 오류를 범할 수 있어서 이에 따른 품질비용의 상승을 수반하게 된다. 또 제품의 품질을 지속적으로 개선하기 위해서는 생산되는 제품의 산포를 줄여야 하는데, 이를 위해서는 측정프로세스에 존재하는 변동량의 원인을 이해하고 정량화하여야 한다. 측정 프로세스 능력 평가는 SQC/SPC에서 가장 먼저 요구되는 분석 절차이다. 측정 프로세스 능력 평가에 관한 대표적인 표준 또는 절차서는 ISO 22514-7, MSA 4, VDA 5 등이 있다. ISO 22514-7(Statistical methods in process management - Capability and performance - Part 7: Capability of measurement processes)은 2012년에 ISO에서 발행한 측정 프로세스 능력 평가 표준이며, MSA 4는 Automotive Industry Action Group(AIAG)가 2010년에 발행한 측정시스템분석 절차서 개정4판이며, VDA 5(Capability of Measuring Systems)는 Verband der Automobilindustrie(독일 자동차산업 협회)에서 2011년에 발행한 측정시스템 능력 평가 절차서 개정2판이다. 본 연구에서는 ISO 22514-7, MSA 4, VDA 5의 분석절차의 내용 및 차이점을 비교하고자 한다.

측정 능력 평가 절차서의 종류(1)

- ISO 22514-7(Statistical methods in process management - Capability and performance - Part 7: Capability of measurement processes)
 - 2012년에 ISO에서 발행한 측정 프로세스 능력 평가 표준임
 - ISO/IEC Guide 98-3, Guide to the expression of the uncertainty in measurement (GUM) 에 의하여 측정 불확도를 파악하여 측정 능력 평가
 - ISO/IEC Guide 99:2007, International vocabulary of metrology — Basic and general concepts and associated terms (VIM)의 용어를 사용함

Year	Document(related matter)	Note(BIPM)
1984	Publication of VIM1	
1993	Publication of VIM2 and GUM	
1995	Publication of Corrected version of GUM (GUM:1995)	
1997	Set up of JCGM(Joint Committee for Guides in Metrology) (←ISO/TAG4)	
2004	Drafting of VIM3	
2007	Publication of VIM3 as ISO/IEC Guide 99:2007	JCGM 200:2008
2008	Publication of GUM:1995 as ISO/IEC Guide 98-3:2008	JCGM 100:2008
2010	Publication of Version with minor corrections of JCGM 100:2008	JCGM 100:2008
2012	Publication of Corrected version of VIM3	JCGM 200:2012

측정 능력 평가 절차서의 종류(2)

- VDA 5(Capability of Measuring Systems)
 - Verband der Automobilindustrie(독일 자동차산업 협회)에서 2011년에 발행한 측정시스템 능력 평가 절차서 개정2판이다.
 - 이 절차서는 2008년에 발행한 ISO/WD 22514-7에 근거하여 측정 프로세스를 평가하고 있다.

참고: ISO의 표준 개발 절차

- ① ISO/WD: 작업초안 (WD: Working Draft)
- ② ISO/DIS: 국제표준초안 (DIS: Draft International Standard)
- ③ ISO/FDIS: 최종국제표준초안 (FDIS: Final Draft International Standard)
- ④ ISO: 국제표준 (IS: International Standard)

측정 능력 평가 절차서의 종류(3)

- MSA 4
 - Automotive Industry Action Group(AIAG)에서 2010년에 발행한 QS-9000의 Reference Manual인 Measurement Systems Analysis 개정4판이다.
 - 1990년에 초판이 발행되었으며, 현재 많은 기업에서 사용하고 있는 측정시스템분석의 대표적인 절차서이다.
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측정 능력 평가 용어(1)

- ISO 22514-7 & VDA 5

[Measuring System]

- set of one or more measuring instruments and often other devices, including any reagent and supply, assembled and adapted to give information used to generate measured quantity values within specified intervals for quantities of specified kinds

NOTE A measuring system may consist of only one measuring instrument.
[VIM3, 3.2]

[Measurement Process]

- set of operations to determine the value of a quantity
[ISO 9000, 3.10.2]
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측정 능력 평가 용어(2)

• MSA 4

[Gage]

- any device used to obtain measurements; frequently used to refer specifically to the devices used on the shop floor; includes go/no-go devices

[Measurement System]

- the collection of instruments or gages, standards, operations, methods, fixtures, software, personnel, environment and assumptions used to quantify a unit of measure or fix assessment to the feature characteristic being measured; the complete process used to obtain measurements.

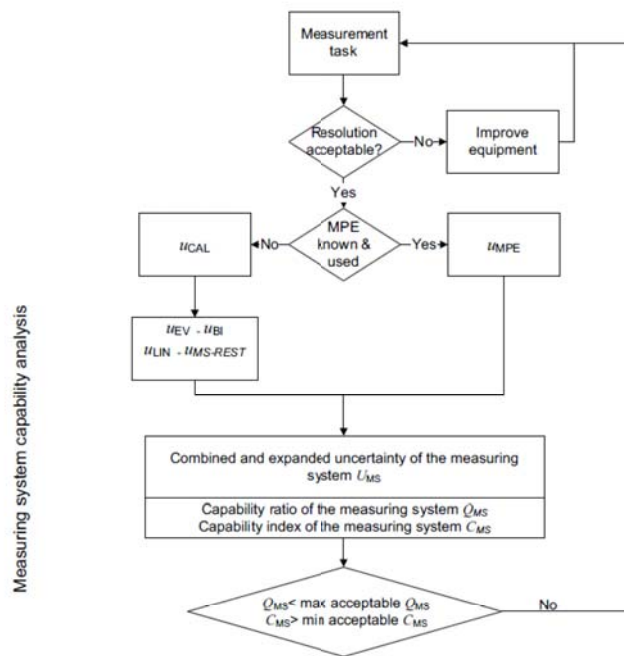
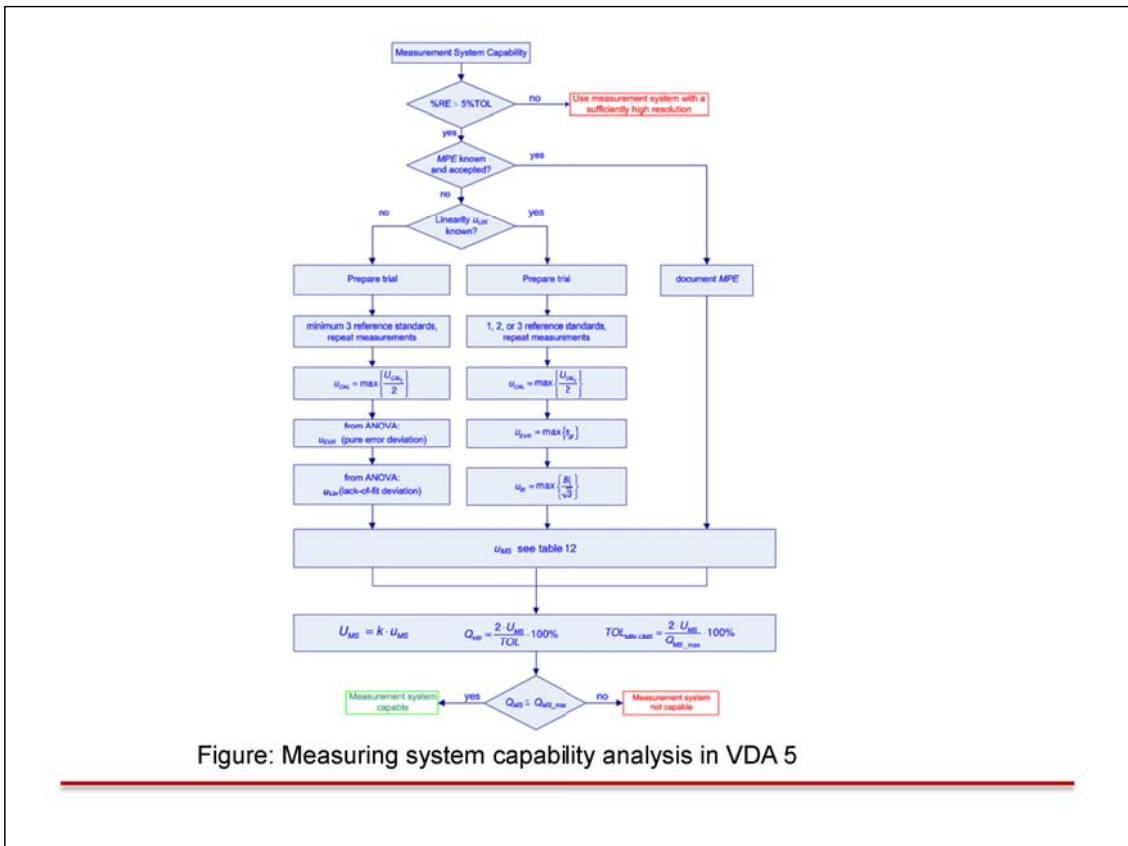
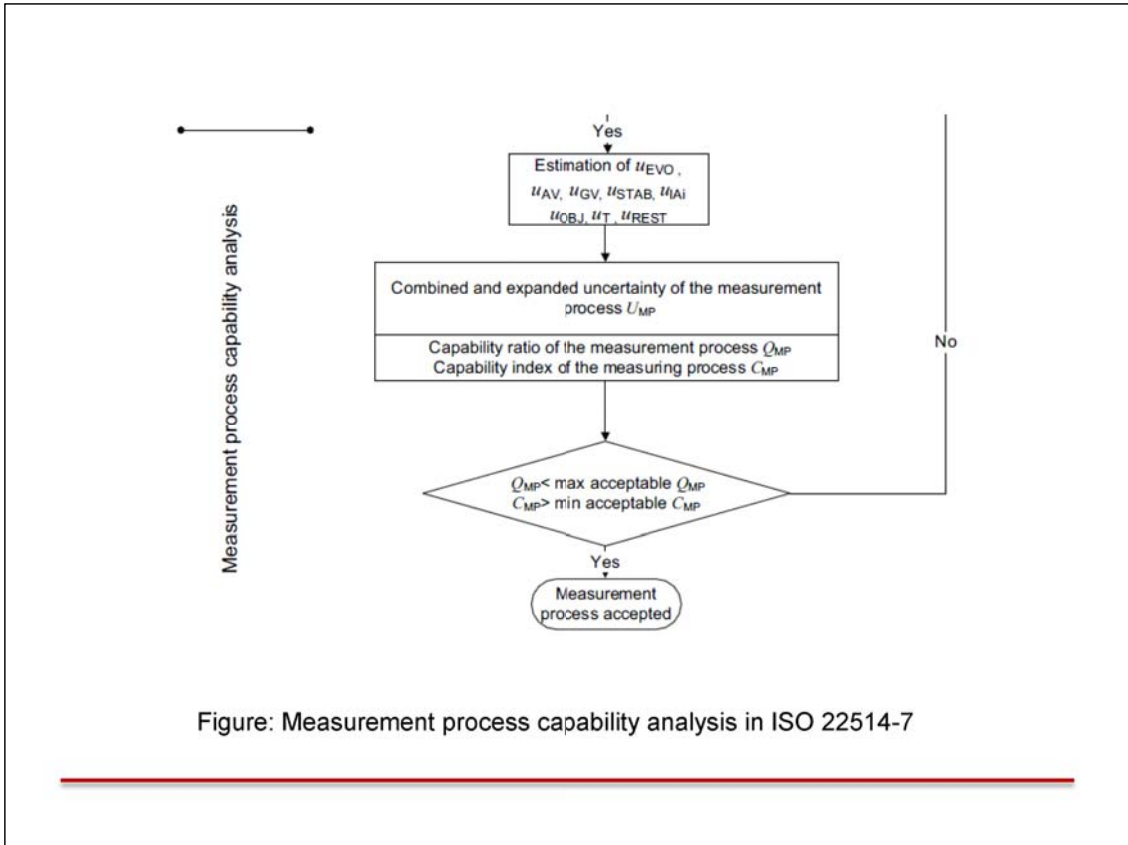
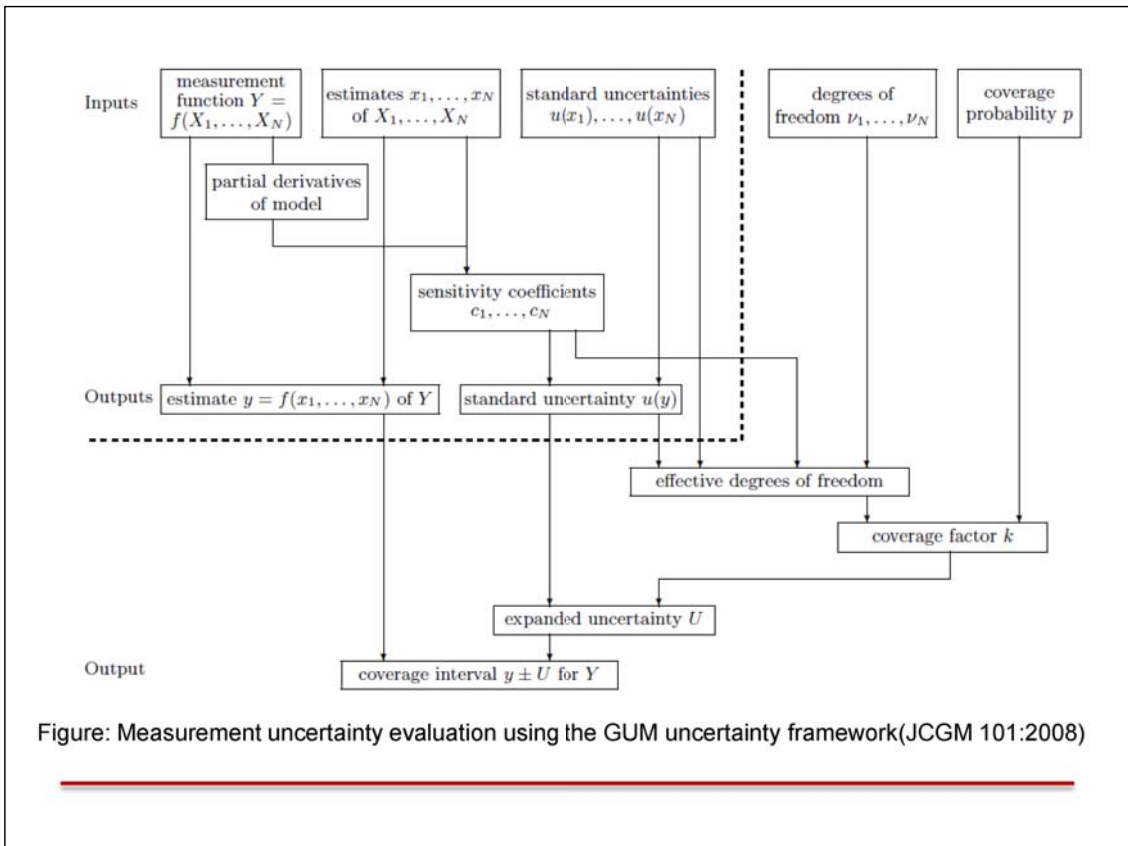
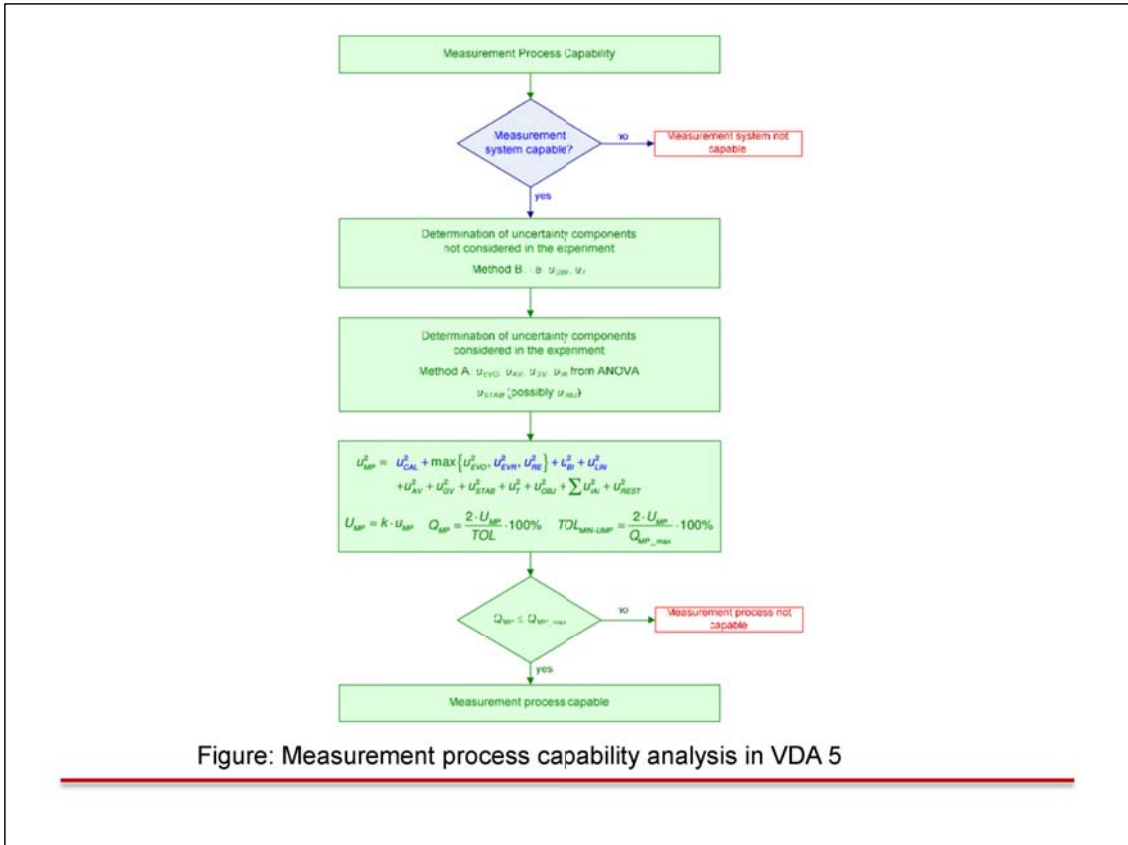


Figure: Measuring system capability analysis in ISO 22514-7





Standard measurement uncertainty : $u(x_i)$

① Type A evaluation of measurement uncertainty:

evaluation of a component of measurement uncertainty by a statistical analysis of measured quantity values obtained under defined measurement conditions

② Type B evaluation of measurement uncertainty:

evaluation of a component of measurement uncertainty determined by means other than a Type A evaluation of measurement uncertainty

Combined standard measurement uncertainty:

$$u(y) = \sqrt{c_1^2 u^2(x_1) + c_2^2 u^2(x_2) + c_3^2 u^2(x_3) + \dots + c_n^2 u^2(x_n)}$$

$$c_i = \partial y / \partial x_i \text{ (sensitivity coefficient)}$$

Expanded measurement uncertainty:

$$U(y) = k \cdot u(y)$$









- ▶ k : coverage factor
- ▶ $k = t(1 - 2/\alpha; \nu_{eff})$
- ▶ ν_{eff} : Welch-Satterthwaite formula

Coverage interval:

interval containing the set of true quantity values of a measurand with a stated probability, based on the information available

$$Y = y \pm U(y) = y \pm k u(y)$$

• Probability density function assignment for some common circumstances

Distribution		Mean & variance
Rectangular: $R(a, b)$		$E(X) = \frac{a+b}{2}, V(X) = \frac{(b-a)^2}{12}$
Curvilinear trapezoid: $CTrap(a, b, d)$		$E(X) = \frac{a+b}{2}, V(X) = \frac{(b-a)^2}{12} + \frac{d^2}{9}$
Trapezoidal: $Trap(a, b, \beta)$ with $a = a_1 + a_2,$ $b = b_1 + b_2,$ $\beta = [(b_1 - a_1) - (b_2 - a_2)] / (b - a)$		$E(X) = \frac{a+b}{2}, V(X) = \frac{(b-a)^2}{24} (1 + \beta^2)$
Triangular: $Trap(a, b)$ with $a = a_1 + a_2,$ $b = b_1 + b_2$		$E(X) = \frac{a+b}{2}, V(X) = \frac{(b-a)^2}{24}$
Arc sine (U-shaped): $U(a, b)$		$E(X) = \frac{a+b}{2}, V(X) = \frac{(b-a)^2}{8}$
Gaussian: $N(\mu, \sigma^2)$		$E(X) = \mu, V(X) = \sigma^2$
Exponential: $Ex(\theta)$		$E(X) = \theta, V(X) = \theta^2$
Gamma: $G(q + 1, 1)$		$E(X) = q + 1, V(X) = q + 1$

Uncertainty components	Symbol	Test/model
Resolution of the measuring system	μ_{RE}	$\mu_{RE} = \frac{1}{\sqrt{3}} \cdot \frac{R_E}{2} = \frac{R_E}{\sqrt{12}}$ <p>where R_E is the resolution and is assumed to follow a rectangular distribution.</p> <p>If analogue scales are used, the actual distribution can be another e.g. normal distribution.</p>

(e.g.) $RE=0.1$
 Test item : 0.05~0.15 → 0.1
 $V(x) = (b-a)^2 / 12 = (RE)^2 / 12$
 $SD(x) = u(x) = RE/\sqrt{12}$

Uncertainty components	Symbol	Test/model
Calibration	μ_{CAL}	<p>Standard deviation of uncertainty due to calibration (from certificate).</p> <p>In cases where the uncertainty in protocol is given as expanded uncertainty, it should be divided by the corresponding coverage factor:</p> $\mu_{CAL} = U_{CAL} / k_{CAL}$



Uncertainty components	Symbol	Test/model
Uncertainty arising from linearity	μ_{LIN}	<p>Instance 1: $\mu_{LIN} = 0$</p> <p>Instance 2: $\mu_{LIN} = \frac{a}{\sqrt{3}}$</p> <p>where a is half width of the range of a uniform distribution or the known MPE-value.</p> <p>Instance 3: μ_{LIN} is determined experimentally together with μ_{EVR} (see instance 2 below)</p> <p>Instance 4: μ_{LIN} is determined based on the results from the calibration certificate</p>
Uncertainty arising from bias	μ_{BI}	<p>From the measurements on a reference standard, μ_{BI} can be calculated based on the distance between the standard and the average of the measured values.</p> $\mu_{BI} = \frac{ \bar{x}_R - x_m }{\sqrt{3}}$
Repeatability using reference standards	μ_{EVR}	<p>Instance 1: minimum 30 repeated measurements on a reference standard, whereby μ_{EVR} can be estimated</p> <p>Instance 2: K repeated measurements on each of the N (≥ 2) different reference standards with $N \cdot K \geq 30$.</p> <p>Estimate from the linear regression function</p> <p>Estimate both μ_{EVR} and μ_{LIN} by the ANOVA method.</p>
Other uncertainty components not included in the above	$\mu_{MS-REST}$	E.g. scale shift (use of different measuring faces)



Resolution(분해능, 해상도)에 대한 기본 요구사항

(1) ISO 22514-7:

- ① 합부판정용: 공차(tolerance)의 1/20 이하
- ② 공정관리용: 공정 변동의 1/5 이하
(ISO 22514-7, p.11)

(2) VDA 5:

공차 대비 5% 이하, 즉 $\%RE = \frac{RE}{U-L} \times 100 \leq 5\%$ (VDA 5, p.53)

(3) MSA 4:

- 공차(혹은 공정 변동)의 1/10 이하 (MSA 4, p.41)
- number of distinct categories(ndc)가 5 이상 (MSA 4, p.47)

Repeatability and bias analysis based on one reference standard

	ISO 22514-7	VDA 5	MSA 4
Procedure name	Repeatability and bias based on one reference standard	Type 1 Study	Guidelines for Determining Bias (Independent Sample Method)
Measurement experiment	at least 30 measurements	at least 25 measurements	at least 10 measurements
Calculations	$u_{MS} = \sqrt{u_{CAL}^2 + u_{BI}^2 + u_{BV}^2 + u_{MS-RBST}^2}$ - $u_{MS-RBST}$: other uncertainty components (measuring system) $U_{MS} = k u_{MS}$ (k : coverage factor)		$\sigma_{repeatability} = s$ $= \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}}$
Performance measures	$Q_{MS} = \frac{2 \cdot U_{MS}}{U-L} \times 100\%$ $C_{MS} = \frac{0.3 \cdot (U-L)}{6 u_{MS}}$	$Q_{MS} = \frac{2 \cdot U_{MS}}{U-L} \times 100\%$ $C_g = \frac{0.2 \cdot (U-L)}{4s}$ $C_{gk} = \frac{0.1 \cdot TOL - Bi}{2s}$	$\%EV = \frac{6s}{TV} \times 100$ t-test ($H_0 : Bias = 0$)
Acceptance criteria	$Q_{MS} \leq 15\%$ $C_{MS} \geq 1.33$	$Q_{MS} \leq 15\%$ $C_g, C_{gk} \geq 1.33$	$\%EV \leq 30\%$ Do not reject H_0

Linearity Analysis

	ISO 22514-7	VDA 5	MSA 4
Procedure name	Linearity analysis based on a minimum of three reference standards	Linearity Analysis with Correction on Measuring Instrument	Guidelines for Determining Linearity
Measurement experiment	-at least 3 reference standards -at least 3 repeated measurements -minimum sample size: 30	-at least 3 reference standards -at least 10 repeated measurements -minimum sample size: 30	-at least 5 reference standards -at least 10 repeated measurements
Regression model	$y_{ij} = \beta_0 + \beta_1 x_{ij} + \epsilon_{ij}$ - x_{ij} : reference value - y_{ij} : measured value		$y_{ij} = \beta_0 + \beta_1 x_{ij} + \epsilon_{ij}$ - x_{ij} : reference value - y_{ij} : bias average
Calculations	$u_{MS} = \sqrt{u_{CAL}^2 + u_{BV}^2 + u_{LIN}^2 + u_{MS-RBST}^2}$ - $u_{BV} = \max\{u_{BVR}, u_{RB}\}$ - $u_{LIN}^2 = MS_{Lack\ of\ Fit}$ - $u_{BVR}^2 = MS_{Pure\ Error}$ - $u_{MS-RBST}$: other uncertainty components (measuring system) $U_{MS} = k u_{MS}$ (k : coverage factor)		$s = \sqrt{MS_B}$
Performance measures	$Q_{MS} = \frac{2 \cdot U_{MS}}{U-L} \times 100\%$ $C_{MS} = \frac{0.3 \cdot (U-L)}{6 u_{MS}}$	$Q_{MS} = \frac{2 \cdot U_{MS}}{U-L} \times 100\%$	$\%EV = \frac{6s}{TV} \times 100$ t-test (H_0 : slope = 0, H_0 : intercept = 0)
Acceptance criteria	$Q_{MS} \leq 15\%$ $C_{MS} \geq 1.33$	$Q_{MS} \leq 15\%$	$\%EV \leq 30\%$ Do not reject H_0

Measurement process capability analysis(1)

	ISO 22514-7	VDA 5	MSA 4
Procedure name	Measurement process capability analysis	Measurement process capability analysis (Type 2 Study)	Guidelines for Determining Repeatability and Reproducibility
Measurement experiment	-minimum of 5 workpieces ① minimum of 3 operators with a minimum of 2 repeated measurements ② minimum of 2 operators with a minimum of 3 repeated measurements -minimum sample size: 30	-minimum of 3 test parts -minimum of 2 operators -minimum of 2 repeated measurements -minimum sample size: 30	-minimum of 10 parts -minimum of 2 operators -minimum of 2 repeated measurements
Analysis model	Two-way ANOVA (random effect model)		
Estimation of variance components	$\hat{\sigma}_p^2 = \frac{MS_p - MS_{op}}{ar}$, $\hat{\sigma}_o^2 = \frac{MS_o - MS_{op}}{pr}$, $\hat{\sigma}_{op}^2 = \frac{MS_{op} - MS_e}{r}$, $\hat{\sigma}_e^2 = MS_e$		

Measurement process capability analysis(2)

	ISO 22514-7	VDA 5	MSA 4
Calculations	$u_{MP}^2 = u_{CAL}^2 + u_{LIN}^2 + u_{BI}^2 + u_{EV}^2 + u_{MS-REBT}^2 + u_{AV}^2 + u_{IA}^2 + u_{STAB}^2 + u_T^2 + u_{REBT}^2$ <p> $-u_{BVO} = \hat{\sigma}_e \quad -u_{AV} = \hat{\sigma}_o \quad -u_{IA} = \hat{\sigma}_{op}$ $-u_{EV} = \max\{u_{EVR}, u_{EVO}, u_{RE}\}$ $-u_{STAB}$: uncertainty caused by stability $-u_T$: uncertainty caused by temperature $-u_{REBT}$: other uncertainty components (measurement process) $U_{MP} = k u_{MP} \text{ (} k: \text{ coverage factor)}$ </p>		$\hat{\sigma}_{GRR} = \sqrt{\hat{\sigma}_o^2 + \hat{\sigma}_{op}^2 + \hat{\sigma}_e^2}$
Performance measures	$Q_{MP} = \frac{2 \cdot U_{MP}}{U-L} \times 100\%$ $C_{MP} = \frac{0.3 \cdot (U-L)}{3u_{MS}}$	$Q_{MP} = \frac{2 \cdot U_{MP}}{U-L} \times 100\%$	$\%GRR = \frac{6\hat{\sigma}_{GRR}}{TV} \times 100$ $ndc = 1.41 \times \frac{\hat{\sigma}_p}{\hat{\sigma}_{GRR}}$
Acceptance criteria	$Q_{MP} \leq 30\%$ $C_{MP} \geq 1.33$	$Q_{MP} \leq 30\%$	$\%GRR \leq 30\%$ $ndc \geq 5$

Capability analysis of attribute measurement processes

	ISO 22514-7	VDA 5	MSA 4
Procedure name	Capability of attribute measurement processes	Capability Analysis of Attribute Measurement Processes	Attribute Measurement Systems Study
Measurement experiment	(1) without using reference values -at least 40 different test parts (At least a proportion(e.g. 40 %) of the test parts should be in the uncertainty range) -3 repeated measurements -minimum of 2 different operators (2) using reference values -MSA 4		<input type="checkbox"/> using reference values -25% of the parts at or close to LSL -25% of the parts at or close to USL
Analysis methods	(1) without using reference values -Bowker Test of symmetry (interrater agreement) (2) using reference values -Signal Detection Theory		① Hypothesis Test ② Calculation method of Effectiveness, Miss Rate, False Alarm Rate ③ Signal Detection Theory
Performance measures	(1) χ^2 Statistics (2) $Q_{attr} = \frac{2U_{attr}}{U-L} \times 100 = \frac{d}{U-L} \times 100$ $-d = (d_{LSL} + d_{USL})/2$		① Kappa Statistics -interrater agreement -correctness ② Effectiveness, Miss Rate, False Alarm Rate ③ $\%GRR = \frac{6\hat{\sigma}_{GRR}}{U-L} \times 100 = \frac{d}{U-L} \times 100$
Acceptance criteria	(1) Do not reject H_0 (2) $Q_{attr} \leq 30\%$		① $Kappa \geq 0.75$ ② $Effectiveness \geq 90\%$ $Miss Rate \leq 2\%$ $False Alarm Rate \leq 5\%$ ③ $\%GRR \leq 30\%$

결론

- MSA 4는 1990년부터 많은 기업 기업에서 사용하고 있는 측정시스템 분석 절차서임
 - ISO 22514-7와 VDA 5는 ISO/IEC Guide 98-3(GUM 1995, JCGM 100)에 의하여 측정 불확도(measurement uncertainty)를 산출하여 측정시스템 및 측정 프로세스를 평가하며, 현재 유럽 자동차 제조회사 및 협력회사, 우주항공회사, ISO/IEC 17025(General requirements for the competence of testing and calibration laboratories)를 인정받은 회사 등에서 사용하고 있는 절차서임
 - 본 연구에서는 ISO 22514-7, MSA 4, VDA 5의 분석절차의 내용 및 차이점을 비교 분석하였음
 - 참고로 부품내 변동을 고려한 측정능력 평가 절차는 ISO 22514-7와 VDA 5에서는 분석 절차가 주어져 있으나, MSA는 1판과 2판까지는 분석 절차가 있었으나 3판부터는 이 절차가 삭제되었음
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참고문헌

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