

Kinematics report

Sample document with complete example values. It shows the report the purchased export produces for YOUR input - it is not itself a report for any part.

Project: Sample project

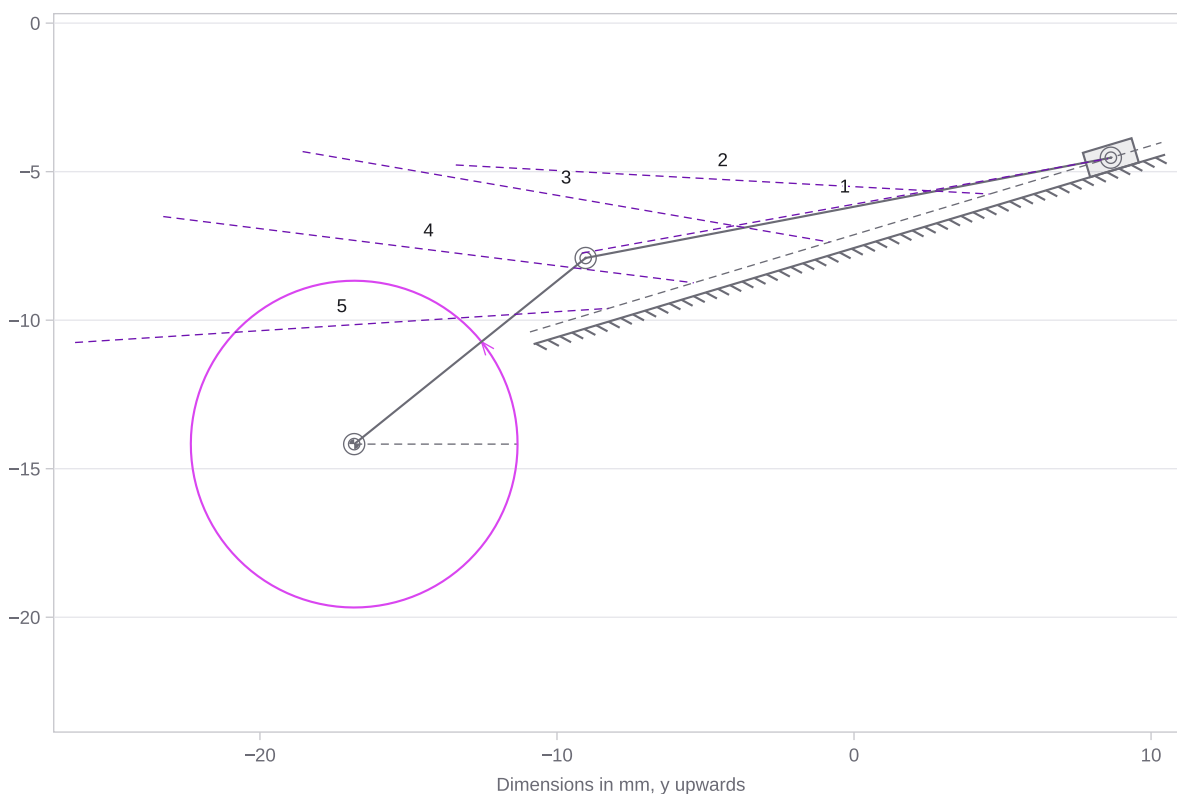
Part/Position: no real part

Prepared by: Sample, not released

Overall assessment: OK — every checked condition is met. Only the rows of the verification table were assessed; everything else is stated as a characteristic value without rating.

This document certifies the MOTION of the linkage described below: its structure, its traverse, the angles, torques and joint forces computed from it, and the accuracy of that computation. It expressly certifies NO strength, no service life, no natural frequency and no manufacturing tolerance. Of freedom from collision it certifies exactly what was checked: the position of the link centre lines relative to the drawn keep-out areas — not the links against each other, not their actual width, and nothing where no keep-out area is given.

System sketch in the initial position



Drawn is the same scene as on screen: frame, links and joints in the neutral tone.

The drive stands out by the circle around its bearing. The arrowheads on it show which way it turns — one for a full revolution, two for a drive that swings between two limits. The horizontal line from the pivot to the circle is the zero direction the arc is read against: the drive angles count from it, anticlockwise, and not from the link line that starts there.

The dashed outlines with the digits are the prescribed positions of the moving plane: they show the shape of the link named below at the location and rotation the author prescribed. They too are a specification and not a result — the mechanism does not necessarily reach them. The digit is the place in the order and not a point in time; the table below states the numbers of each.

Computation

Steps per traverse	360
Positions computed	361
Duration of one traverse	6.283 s
Mean speed of the drive	9.549 1/min

Gravity (positive acting downwards)	9.81 m/s ²
Position shown	0
Superimposed positions in the system sketch	0
Prescribed positions, plane of	koppel
Prescribed positions, count	5

Position synthesis: the chosen solution

Solution character of the task	five positions — zero, two or four Burmester points
Input dyad A ₀ –A (centre point circle point)	–16.83 –14.17 –9.17 –7.74 mm
Output dyad: sliding guide (circle point track direction)	8.55 –4.56 mm 16.6992°
Link length A ₀ A	10 mm
Largest spread of the link lengths across the positions	9.57E-9 mm
Offset of the guide from A ₀	1.9157 mm
Overall size (largest of crank, coupler and e)	18 mm
Link length ratio longest/shortest link	1.8
Distance of the farther ground pivot, in task scales	0.601
Fully rotating link	at the input pivot A ₀
Running behaviour of the slider crank	fully rotating (coupler > crank + e), offset
Smallest transmission angle μ over the arc travelled	48.55 °
Measured over	the full rotation of the input
With the input at the other ground pivot (B ₀ instead of A ₀)	not applicable — the second dyad is a sliding guide, and a slider does not rotate. There is no second ground pivot to move the input to.

Links

Link	x ₀ [mm]	y ₀ [mm]	φ ₀ [°]	Link line [°]	m [kg]	s _S [mm]	J _S [kg·mm ²]
gestell	0	0	0	—	—	at the reference point	—
kurbel	–16.83	–14.17	40	40	—	at the reference point	—
koppel	–9.17	–7.74	10.2	10.2	—	at the reference point	—
Slider kolben	8.55	–4.56	16.7	—	—	at the reference point	—

Joints

Joint	Type	Links	Attachment 1 [mm]	Attachment 2 [mm]	Extra
fest	Ground constraint	gestell	0 0	—	φ = 0°
A0	Revolute joint	gestell – kurbel	–16.83 –14.17	0 0	without friction
A	Revolute joint	kurbel – koppel	10 0	0 0	without friction
B	Revolute joint	koppel – kolben	18 0	0 0	without friction
S	Prismatic joint	gestell – kolben	–65.27 –26.7	0 0	axis direction 16.699244°; Δφ = 16.7°; without friction

Drives

Drive	Link	from φ [°]	to φ [°]	Offset to link line [°]	Segments	Transitions
1	kurbel	38.8	398.8	—	linear across the whole range	free of shock and jerk

Prescribed positions of the moving plane

No.	Name	x [mm]	y [mm]	φ [°]
1	L1	–9.167	–7.744	10.192
2	L2	–13.407	–4.775	–3.117
3	L3	–18.564	–4.324	–9.746

No.	Name	x [mm]	y [mm]	φ [°]
4	L4	-23.255	-6.512	-7.118
5	L5	-26.224	-10.752	3.662

Check: does the mechanism reach the prescribed positions?

No.	Name	Input angle φ [°]	Progress τ	Residual deviation [mm]	Result
1	L1	40	0.0033	1.37E-12	reached
2	L2	70	0.0867	5.17E-9	reached
3	L3	100	0.17	6.98E-9	reached
4	L4	130	0.2533	7.89E-9	reached
5	L5	160	0.3367	4.75E-9	reached

Structure and degree of freedom

Links n (including the frame)	4
Ground constraints	1
Simple joints g_1 (revolute and prismatic)	4
Higher joints g_2 (cam joints, gear pairs, rack-and-pinion pairs, Geneva drives)	0
Drives	1
Degree of freedom $F = 3 \cdot (n - 1) - 2 \cdot g_1 - g_2$ (Grübler)	1

Verifications

Criterion	Value	Limit	Status
Degree of freedom F, required 1 (number of drives)	1	1	● OK
Drive range complete and without gaps			● OK
Transitions free of shock and jerk			● jerk-free
All prescribed positions are reached			● OK

Check: does the mechanism reach the prescribed positions?

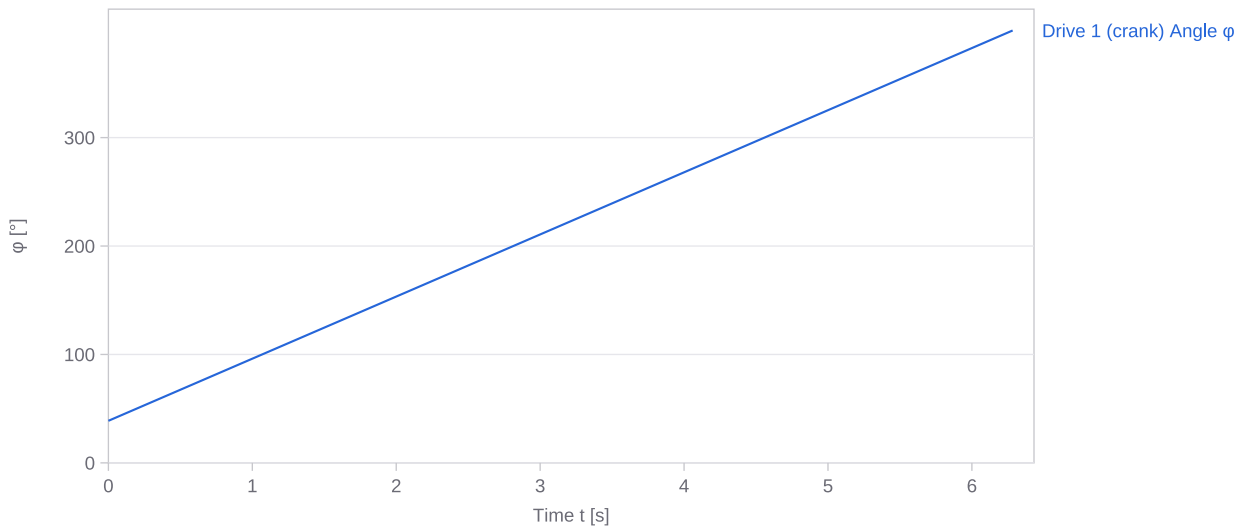
Result	The mechanism reaches every prescribed position, in the prescribed order.
Order in which they are traversed	1 → 2 → 3 → 4 → 5
Order read cyclically (the input comes all the way round)	yes
Bound below which a position counts as reached	1.8E-5 mm

Characteristic values

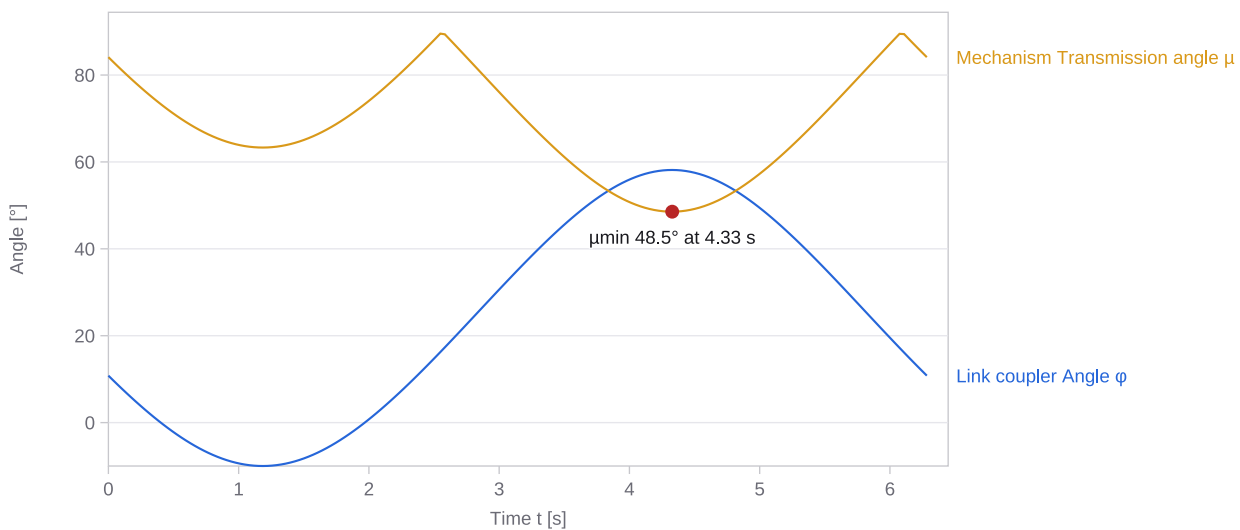
Smallest transmission angle $\mu_{\min}$	48.5°
Largest deviation from the target path	no target path drawn
Largest penetration into a blocked area	no blocked area drawn
Smallest locking factor $r_{\min}$ (self-locking)	no μ_0 entered
Largest drive torque $M_{\max}$	no load in the model
Largest joint force $F_{\max}$	no load in the model
Largest drive power $P_{\max}$	no load in the model
RMS torque M_{rms} at the drive	no load in the model
Largest reduced inertia $J_{\text{red,max}}$ at the drive	no load in the model
Smallest reduced inertia $J_{\text{red,min}}$ at the drive	no load in the model
Largest shaking force $F_{R,\max}$	no load in the model
Type according to Grashof	not a four-bar
Shortest link	not a four-bar
Grashof excess $(s + l) - (p + q)$	not a four-bar
Position of $\mu_{\min}$ (drive angle)	-73.2°
Reversal positions of the output link	2
Stroke of the output link s_0	20.17 mm

Time ratio of forward to return stroke 1.117
Smallest quality index 0.680

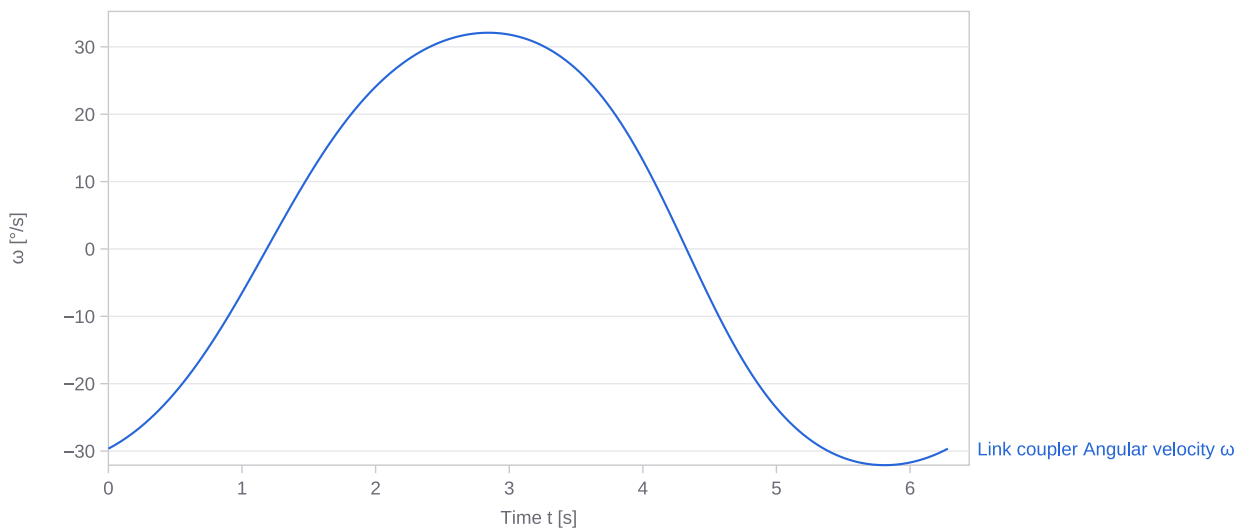
Drive angle over time [°]



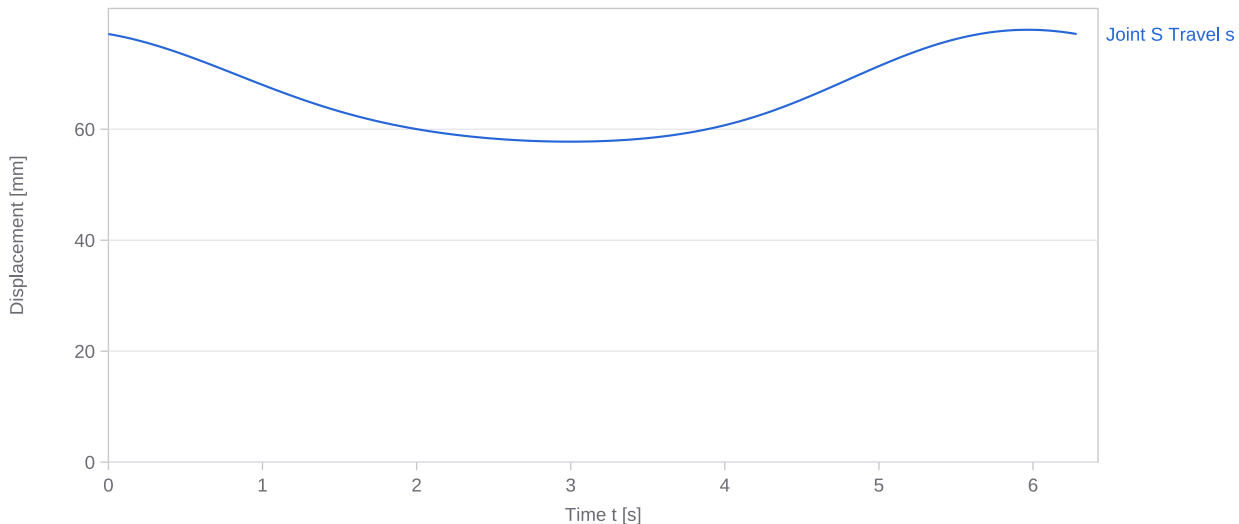
Angle over time [°]



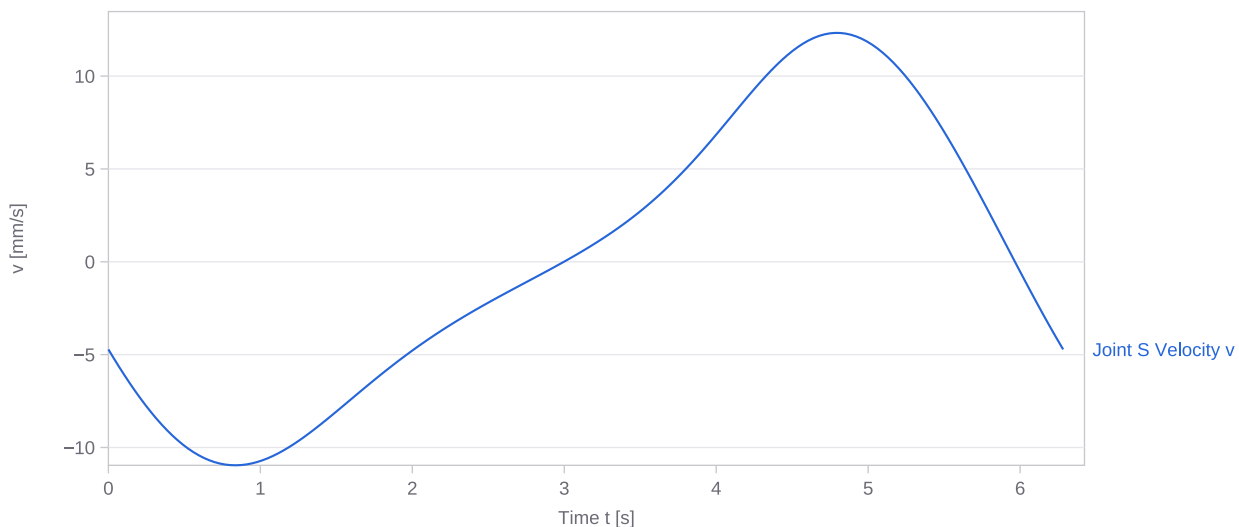
Angular velocity over time [°/s]



Displacement over time [mm]



Velocity over time [mm/s]



Basis of calculation and model assumptions

The closed constraint equations of the planar linkage are solved: for every progress τ on the common timeline the position of all links is found by Newton's method, after which velocity and acceleration are obtained from the same Jacobian. Drive torque and joint forces follow from d'Alembert's principle (kinetostatics) with the masses and inertias given. The motion laws of the segments are the normalised time laws of VDI 2143.

WHERE THE MASS ACTS: the mass of a link acts at its centre of mass s_S , which the table of links below states for every link. When a mass is entered on screen while the centre-of-mass fields are empty, the tool prefills them visibly — with the midpoint between the two revolute joints of the link, or with the mean of them where there are more than two; a prismatic joint does not count, because its attachment location along the guide is arbitrary. The suggestion can be overwritten, a centre of mass already set is left alone, and a loaded state is not touched. Where the table reads "at the reference point", none was given, and it coincides with the build location of the link — a joint for everything this tool creates. The entered mass is then not a mass distributed over the link but a point mass in that joint. The consequence has been measured: on the four-bar linkage 10 kg on the crank thus have no effect at all on the drive torque, and on the coupler only through their weight. The moment of inertia J_S refers to the centre of mass; the parallel-axis term $m \cdot s_S^2$ is added by the computation itself.

WHEN MASSES HAVE NO EFFECT AT THE DRIVE: a link running at constant speed about a fixed axis needs no drive torque — no matter where its centre of mass sits or how large its inertia is: its centrifugal force points through the axis and has no lever arm there, and the link is not accelerated. The prefilled centre of mass changes nothing about this, it merely moves where the centrifugal force acts. Mass takes effect through gravity, through a motion law on the drive, or on a link that does not run at constant speed. Where none of this applies, all that is left of drive torque and drive power are the last bits of the computation.

Both are therefore compared against the load this model can carry at all and are dropped once they lie nine orders of magnitude below it; the row then states the reason and NO limit — a figure of that magnitude would fall below any limit and thereby pass a check that never took place. The joint force is not affected and is still reported: the centrifugal force of the crank is a real bearing force, it merely lacks a lever arm about the drive axis.

HOW THE CHARACTERISTIC VALUES ARE OBTAINED: the transmission angle μ is defined for two configurations — for the four-bar chain as the angle between coupler and rocker at joint B, for the slider-crank between coupler and the normal to the guide line (Kerle/Pittschellis/Corves 2007, p. 161, eq. 6.5 and 6.6). The acute value is reported, and as $\mu_{\min}$ the smallest across all computed positions; the closed form given in the source holds for a full revolution and is therefore not applied but only used as a cross-check. For any other chain the row states that the quantity is not defined there. At a cam joint it appears as the pressure angle $\alpha = 90^\circ - \mu$ in a row of its own. If a cylinder sits on the chain, the chain is taken without it, and a row of its own reports the transmission angle at the cylinder: $\mu = 90^\circ - \alpha$ between the cylinder axis and the motion of its rod-end point relative to the base. As a guide value the same source gives $40^\circ \leq \mu \leq 50^\circ$ for slow-running mechanisms (p. 160, eq. 6.4); that is experience and not a standard — VDI 2130 devotes a section to the transmission angle and names no figure. The row therefore carries the wording of a guide value and not that of a passed verification: at 39° nothing breaks, but bearing forces, friction and sensitivity to backlash grow quickly. The output link is taken to be the non-driven link attached to the frame by a revolute joint; its reversal positions are the zero crossings of its angular velocity, interpolated linearly between two grid points. If it stands still in a dwell and moves back afterwards, the dwell is one reversal; over a closed cycle a dwell across the start of the cycle counts as well. If a reversal lies in a dwell, the time ratio is omitted, because which side the dwell time belongs to would be a convention. If it reverses exactly twice, the swing angle ψ_0 follows as its full excursion and the time ratio as the longer of the two intervals divided by the shorter, hence always ≥ 1 . The time ratio refers to TIME and not to crank angle: with a uniformly running drive the two are the same; if a segment carries a motion law they part company, and time is what counts. It is only stated for a drive that completes at least one full revolution — otherwise there is no return stroke to measure against. If the output link instead slides in a guide on the frame — the piston of the slider-crank, the follower of a cam mechanism —, its velocity along the guide counts, and the stroke $s_0 = s_{\max} - s_{\min}$ in millimetres takes the place of the swing angle, as fine as the grid. The same holds if the link at the frame rotates through a closed cycle without a reversal and a ram slides behind it, as in the Whitworth quick return. Where no unique output link can be found, the rows are absent: that applies to any mechanism with more than one drive, such as the five-bar — which of its links would be the output is not something the structure states. The swing angle is measured across the computed positions and is therefore as fine as the grid; at 360 steps it sits about 0.002° below the closed-form value. The drive power is, in every position, the sum over the drives of torque times angular velocity, and $P_{\max}$ its largest magnitude across the traverse — not $M_{\max}$ times $\omega_{\max}$, because with a motion law the two peaks do not coincide.

TYPE ACCORDING TO GRASHOF: whether a link of the four-bar chain of revolute joints rotates fully is decided by the four link lengths alone. With s the shortest, l the longest and p, q the remaining two, the condition reads $s + l < p + q$; the Grashof excess stated is the difference $(s + l) - (p + q)$ and is therefore negative wherever the condition holds. If it holds, the type follows from where the shortest link sits: at the frame a crank-rocker, as the frame itself a double crank, as the coupler a double rocker. For equality the mechanism is a change-point linkage and hence not run-safe — it passes through the aligned position, but which branch it takes afterwards is not determined. If the condition is violated, all four joints merely oscillate (triple rocker). A prismatic joint or a fifth link makes it a different chain, for which there is no Grashof type; the row then says exactly that. The type is a statement about running behaviour and not a grade — it is not assessed.

HOW THIS MECHANISM WAS COMPUTED FROM THE PRESCRIBED POSITIONS — exact position synthesis after Burmester: sought are points a of the moving plane that keep the same distance from a ground-fixed point b in ALL prescribed positions; such a pair is a dyad, and two dyads make a four-bar. Computed is the real vector form of Angeles/Bai, equation (2): $b^T \cdot (E - Q_j) \cdot a + r_j^T \cdot Q_j \cdot a - r_j^T \cdot b + \frac{1}{2} \cdot r_j^T \cdot r_j = 0$, with the rotation matrix Q_j of the j -th position and its displacement r_j against the reference position; the raised T denotes the transpose, just as the underscore denotes the index throughout this document. It follows from expanding and halving the requirement $\|(r_j - b) + Q_j \cdot a\|^2 = \|a - b\|^2$; all four terms are lengths squared, and for the reference position itself ($Q = E, r = 0$) it becomes identically zero — which is why the first position yields no condition and $m = \text{number of positions} - 1$ equations remain. The equation is BILINEAR in a and b , and the whole solution character follows from that: with TWO positions a single equation remains, and for a fixed circle point it is the perpendicular bisector of its two positions — every point on it is an admissible centre, the solution set is therefore three-parametric and there is no unique target value; all perpendicular bisectors pass through the pole of rotation P_{12} , the fixed point of the motion, and the pole rotation angle ϕ_{12} is halved there into $\alpha_{12} = \phi_{12}/2$. With three positions two equations face four unknowns, so every point of the plane is a circle point and its centre point follows LINEARLY; with four positions a one-parametric family remains whose circle points lie on a cubic — the Burmester curve; with five positions there are zero, two or four individual points. Source of the method: J. Angeles, S. Bai, "Some Special Cases of the Burmester Problem for Four and Five Poses", DETC2005-84871, ASME IDETC 2005, eqs. (1a) and (2). Three further, mutually independent sources present the same method: R. Braune, "Die

klassische Genaulagen-Synthese von Getrieben mit Dreh- und Schubgelenken", Getriebetechnik-Kolloquium Siegen 2007 (German account, sections 2.2 and 2.3), the standard dyad form of kinematic synthesis, and Hartenberg/Denavit with the geometric construction via perpendicular bisectors. The historical source is Burmester, Lehrbuch der Kinematik, volume one, Leipzig 1888, ninth section.

HOW THE CHECK IS CARRIED OUT: that a circle point keeps the same distance in all positions does NOT yet mean that the built mechanism also travels through those positions — it only means it CAN take them up. The check is therefore made on the mechanism as it runs. The input angle of each position is not searched for but fixed: the crank points from the centre point to its circle point, and where that sits in the j -th position is known from the prescribed positions. At exactly that angle the constraint equation is solved, warm-started from the nearest state of the run that comes from the home position — the warm start is the actual statement: it says which assembly configuration the mechanism is in when driven there from its home position. THE HOME POSITION IS THE FIRST PRESCRIBED POSITION, because the input range of a mechanism built from positions is anchored to the task and not to the swing arc: it runs from the first prescribed position across all the others, and the edge strip of one per cent lies OUTSIDE that span. If the remaining positions lie below the first in angle, the range runs backwards — that is not a quirk of the method but the only way to let a mechanism start in its first prescribed position. Measurement is at TWO moving points, namely both circle points; two points fix location and rotation of a plane together, a single one would leave the rotation unchecked. The column "residual deviation" states the larger of the two distances. A position counts as reached if it lies below the bound stated; the bound is one millionth of the larger of task scale and longest link — about a thousandfold above computational accuracy and a thousandfold below the closest measured failure. The five results of the column mean different things and call for different answers: "reached" is the intended case; "in the edge strip" means the position is taken up but lies just outside the delivered input range — since that range is anchored to the task, this only occurs when at most ONE prescribed position lies within the swing arc and there is consequently nothing to anchor to; "other assembly" means the mechanism takes the position up but could only get there by being taken apart and reassembled; "not reachable" means the input never attains that angle; "no assembly" means the chain does not close there at all. The ORDER is checked as well. If the input comes all the way round, the order is read cyclically — a full rotation has no beginning, and the sequence 2, 3, 1 is the same motion as 1, 2, 3. For a rocking input this does not hold: it runs from one limit position to the other, and there the beginning is fixed.

WHAT THE CHECK DOES NOT SAY: it verifies THAT and in what ORDER the positions are traversed — not WHEN. This task carries no time specification per position; whoever needs one applies a motion law at the input and reads the times from the diagrams. What is prescribed, moreover, is the POSITION OF A PLANE and not a path: between two prescribed positions the coupler travels the path that the kinematics produces, and the synthesis says nothing about that intermediate path — not even whether it is free of collisions. Branch and rotatability are properties of the mechanism TOGETHER WITH the choice of input: the table applies to the input at pivot A_0 as this mechanism carries it; for the input at the other pivot the result is stated as a separate row above. Finally, a dyad may also be a SLIDING guide — a solution whose centre point lies at infinity, and which together with a revolute dyad forms a slider crank. It is verified by the same check as any other; the three kinds of failure are named alike there, only the two assembly configurations are no longer separated by a line through two ground pivots but by whether the slider sits before or behind the foot of the perpendicular from the crank pin onto the guide. The revolute dyad always carries the input: a slider does not rotate and cannot take an angular drive. TWO sliding guides therefore make no mechanism in this tool — their elliptic trammel is movable, but has no rotating ground link.

WHAT THE DRIVE ANGLE REFERS TO: the columns "from φ " and "to φ " of the drive table give the absolute angle φ of the driven link against the horizontal, measured about its reference point and anticlockwise. It is the same QUANTITY the link table lists as φ_0 , but not necessarily the same NUMBER: the link table gives the STORED design, that is the position in which the linkage was built, and for the solver that is merely a starting value. At $\tau = 0$ the solver imposes "from φ " on the driven link and solves the chain from there; where φ_0 and "from φ " differ, the drawn initial position therefore stands beside the figures of the link table by that difference, and "from φ " governs everything computed. For a linkage computed from prescribed positions this difference is the rule and not an inaccuracy: the design is stored in the prescribed position at which the drive range begins — as a rule the first one — and the range starts one percent of the position span BEFORE it, but at most one percent of the distance to the limit position beyond which the chain no longer closes. The prescribed position thus lies safely inside the drive range and not on its edge, where rounding alone would decide whether it still belongs to it; the check table gives it as a progress τ just above zero. The drive angle is expressly NOT the direction of the drawn link line between two joints: between the two lies the constant angle that the head point has in the moving frame of the link itself. The column "Offset to link line" gives that angle per link line wherever it is not zero, and a dash stands where there is nothing to give. An offset of 180° , for instance, means that in the drawing the link line points exactly opposite to the drive angle, although both describe the same link.

The quality index states how far the linkage stays clear of a dead-centre position, not how load-bearing it is. It is, across the traverse, the smallest value of the geometric mean of the singular values of the non-dimensionalised Jacobian — known in robotics as Yoshikawa's manipulability. It is 0 in a dead-centre position and approaches 1 the more perpendicular the columns

are. Where it approaches zero the linkage passes through a dead centre — joint forces and angular accelerations are unreliable there. Before that, every position is iterated until the chain closes: until the largest remaining gap of the constraint equations falls below 10^{-10} , at most 40 Newton steps. A position that does not get there is not part of this document; it is reported as a gap in the drive range — the row "Drive range complete and without gaps" says so.

Model assumptions: all links are rigid, all joints free of backlash. The computation is without backlash and without elasticity; positions follow first-order theory. Friction is computed only at those joints for which the joint table states a coefficient of friction. Only drawn keep-out areas are checked, and only where some are given; the links are NOT checked against each other. Two links may therefore pass through one another in the calculation without anything being reported here.

The drive torque and the largest joint force stated are INPUT QUANTITIES for a strength verification, not a substitute for one. For a shaft under this torque the verification to DIN 743 applies, for a plain bearing the load rating, for a pin the surface pressure and shear verification.

About this sample

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