**FUNDAMENTALS OF TOOL DESIGN**

Cutting Tool Design

**SCENE 1.**  
**CT49A, CGS: Multipoint Cutting-Tool Design**  
white text, centered on background  
**FTD01B, motion background**

**SCENE 2.**  
**CT50A, tape FTD07, 06:53:37:00-06:54:00:00**  
milling cutter slowly turning  
**CT50B, tape FTD07, 06:54:13:00-06:54:23:00**  
same milling cutter milling cast iron

**NARRATION (VO):**  
MULTIPOINT CUTTING TOOLS ARE A SERIES OF SINGLE-POINT CUTTING TOOLS MOUNTED IN OR INTEGRAL WITH A HOLDER OR BODY AND OPERATED IN SUCH A MANNER THAT ALL THE TEETH OR CUTTING EDGES FOLLOW ESSENTIALLY THE SAME PATH ACROSS THE WORKPIECE.

**SCENE 3.**  
**CT51A, tape FTD20, 21:05:24:00-21:05:46:00**  
c.u. drilling operation  
**CT51B, tape FTD01, 01:15:49:00-01:16:15:00**  
zoom out, milling operation

**NARRATION (VO):**  
MOST MULTIPOINT CUTTING TOOLS CREATE DISCONTINUOUS CHIPS THAT ARE CARRIED FOR SOME DISTANCE BEFORE EJECTION. ADEQUATE CHIP SPACE MUST BE PROVIDED TO PREVENT JAMMING AND TOOL BREAKAGE. WHEN DESIGNING MULTIPOINT TOOLS, CARE MUST BE TAKEN TO PROVIDE SUFFICIENT CHIP SPACE WITHOUT LOSING TOO MUCH RIGIDITY IN THE TOOL. THE AMOUNT AND SHAPE OF THE CHIP SPACE NEEDED DEPENDS ON THE WORKPIECE MATERIAL AND TYPE OF CUT.

**SCENE 4.**  
**CT52A, tape FTD20, 21:11:23:00-21:11:38:00**  
milling operation

**NARRATION (VO):**
FOR DISCONTINUOUS CHIPS, LESS ROOM AND CLOSER TOOTH SPACING CAN BE USED THAN FOR CONTINUOUS CHIPS. CHIPBREAKERS ARE OFTEN INCLUDED ON THE CUTTING FACE TO REDUCE CHIP SIZE AND ENHANCE THE TOOL'S ABILITY TO CONVEY CHIPS.

NARRATION (VO):
CUTTING EDGES CAN BE STRAIGHT OR CONTOURED AND MAY BE EITHER LINEAR TRAVEL..., OR ROTARY TRAVEL.

NARRATION (VO):
WITH THE LINEAR-TRAVEL, THE RELATIVE MOTION BETWEEN TOOL AND WORKPIECE IS ALONG A STRAIGHT LINE PATH.

NARRATION (VO):
WITH THE ROTARY-TRAVEL, THE TOOL TEETH REVOLVE ABOUT THE TOOL AXIS. THE RELATIVE MOTION BETWEEN THE TOOL AND WORKPIECE CAN BE AXIAL..., OR IN A PLANE PERPENDICULAR TO THE TOOL AXIS..., OR SOMETIMES A COMBINATION OF THE TWO AS WITH CERTAIN FORM-GENERATING TOOLS.

--- TOUCH BLACK ---

NARRATION (VO):
THERE ARE NUMEROUS MULTITOOTH CUTTING
Twist Drill
Face Mill
CT56C, tape HSM06, 07:19:34:00-07:20:30:00

high speed milling operation

TOOLS. A FEW OF THE MOST COMMON INCLUDE:
THE BROACH,
THE TWIST DRILL,
AND FACE MILL.

--- TOUCH BLACK ---

SCENE 9.
CT57A, tape 766, 02:05:35:00-02:05:49:00
c.u. pan of broach
CT57B, tape 781, 20:20:34:00-20:20:50:00
c.u. broaching operation

NARRATION (VO):
THE BROACH IS THE MOST COMMON
MULTIPOINT, LINEAR-TRAVEL CUTTING TOOL
AND IS USED FOR PRODUCING EITHER
EXTERNAL OR INTERNAL SURFACES IN A
VARIETY OF PROFILES.

SCENE 10.
CT58A, tape FTD20, 22:12:12:00-22:12:46:00
zoom out, broaching operation
CT58B, CGS: Face Angle
Back-Off Angle
Face-Angle Radius
Back-Of-Tooth Radius
Land
Tooth Depth
Chip Space
Pitch

NARRATION (VO):
BROACH TEETH ARE MADE UP OF SEVERAL
ANGLES AND GEOMETRIES TO SUCCESSFULLY
CUT SHAPES, INCLUDING:
THE FACE ANGLE,
BACK-OFF ANGLE,
FACE-ANGLE RADIUS,
BACK-OF-TOOTH RADIUS,
LAND,
TOOTH DEPTH,
CHIP SPACE,
AND PITCH.

SCENE 11.
CT59A, CGS: Face Angle
CT59B, ANI: c.u. broach tooth
CT59C, ANI: face angle lines

NARRATION (VO):
THE FACE ANGLE, WHICH IS ALSO CALLED THE
HOOK ANGLE, IS THE ANGLE OF THE CUTTING
EDGE OF A BROACH TOOTH.
SCENE 12.
continue graphic
CT60A, CGS: Back-Off Angle
CT60B, ANI: back-off angle lines

NARRATION (VO):
The back-off angle is the relief clearance in back of the cutting edge of the broach tooth. Back-off angles are quite low, typically one-half to three-and-a-half degrees.

SCENE 13.
continue graphic
CT61A, CGS: Face-Angle Radius
CT61B, ANI: face angle radius arrow

NARRATION (VO):
The face-angle radius is the radius just below the cutting edge of the tooth.

SCENE 14.
continue graphic
CT62A, CGS: Back-Of-Tooth Radius
CT62B, ANI: back-of-tooth radius arrow

NARRATION (VO):
The back-of-tooth radius is the radius on the back of the cutting edge of the tooth.

SCENE 15.
continue graphic
CT63A, CGS: Land
CT63B, ANI: land lines

NARRATION (VO):
The land is the thickness of the broach tooth at its top.

SCENE 16.
continue graphic
CT64A, CGS: Tooth Depth
CT64B, ANI: root reference line
CT64C, ANI: tooth depth line

NARRATION (VO):
The tooth depth is the height of the tooth from the root to the cutting edge.

SCENE 17.
continue graphic
CT65A, CGS: Chip Space
CT65B, ANI: chip space highlight

NARRATION (VO):
The chip space, which is also referred to as the chip gullet, is the space between broach teeth which accommodates chips during cutting.

SCENE 18.
continue graphic
CT66A, CGS: Pitch

NARRATION (VO):
THE PITCH IS THE MEASUREMENT FROM THE CUTTING EDGE OF ONE TOOTH TO THE CORRESPONDING POINT ON THE NEXT TOOTH.

NARRATION (VO):

IN OPERATION, EACH TOOTH ON THE BROACH IS GENERALLY HIGHER THAN THE PRECEDING TOOTH. AS A RESULT, THE DEPTH OF CUT, OR CHIP LOAD, INCREASES WITH EACH TOOTH AS THE BROACHING OPERATION PROGRESSES.

TOOTH SHAPE AND CHIP SPACE DEPEND ON WORKPIECE LENGTH, CHIP THICKNESS PER TOOTH AND TYPE OF CHIP MADE.

NARRATION (VO):

BROACHES TEETH ARE TYPICALLY GROUPED INTO THREE DISTINCT REGIONS:

ROUGHING TEETH, WHICH MAKE THE FIRST, GENERALLY HEAVIER CUTS IN A BROACHING OPERATION,

SEMIFINISHING TEETH, WHICH TAKE SMALLER, SEMIFINISHING CUTS,

AND FINISHING TEETH, WHICH ARE ARRANGED AT A CONSTANT SIZE FOR FINISHING.

NARRATION (VO):

BROACHES ARE COMMONLY PRODUCED FROM HIGH-SPEED STEEL OR MAY EMPLOY INDEXABLE CARBIDE INSERTS.

--- TOUCH BLACK ---
THE TWIST DRILL IS A ROUGHING TOOL AND IS THE MOST COMMON AXIALLY-FED ROTARY TOOL USED IN HOLEMAKING OPERATIONS. EITHER THE ROTATING DRILL IS FED INTO A STATIONARY WORKPIECE, OR A STATIONARY DRILL IS FED INTO A ROTATING WORKPIECE.

THE THREE ELEMENTAL PARTS OF THE TWIST DRILL INCLUDE THE SHANK..., FLUTES..., AND DRILL POINT.

THE SHANK IS THE MEANS BY WHICH THE DRILL IS HELD AND DRIVEN. TWIST DRILL SHANKS MAY BE STRAIGHT OR TAPERED.

FLUTES LET COOLANT INTO AND CARRY CHIPS OUT OF THE HOLE BEING PRODUCED. BOTH OF THESE FUNCTIONS ARE ESSENTIAL FOR THE DRILL POINT TO CONTINUE CUTTING UNDER THE SEVERE CONDITIONS OF ROTATING AT HIGH SPEED IN AN ENCLOSED SPACE.

THE HELIX ANGLE OF A DRILL'S FLUTES CAN VARY DEPENDING ON THE MATERIAL TO BE
drill with high helix angle
CT74D, tape 80, 03:06:39:00-03:06:48:00
drill with low helix angle

SCENE 27.
CT75A, CGS: Drill Point
CT75B, tape 78, 01:25:46:00-01:25:55:00
c.u. twist drill point entering work

SCENE 28.
CT76A, ANI: drill, showing cutting lips, chisel edge
CT76B, ANI: arrow 1
CT76C, ANI: arrow 2
CT76D, CGS: Cutting Lips
CT76E, CGS: Chisel Edge
CT76F, ANI: drill
CT76G, ANI: chisel edge arrow
CT76H, ANI: drill web
CT76I, ANI: drill web arrow 1
CT76J, ANI: drill web arrow 2
CT76K, CGS: Drill Web

SCENE 29.
CT77A, ANI: drill web
CT77B, tape 728, 15:15:00:00-15:15:22:00
holemaking operation
CT77C, tape FTD19, 20:15:53:00-20:16:10:00
holemaking operation

SCENE 30.
CT78A, ANI: standard drill point
CT78B, ANI: standard drill point lines

NARRATION (VO):

Drilled. A standard helix angle of 25 to 33 degrees is optimal for steels and cast irons,..., a high helix or fast spiral angle of 35 to 40 degrees is used for low-strength materials like aluminum,..., and a low-helix or slow-spiral angle of 15 to 20 degrees is used for drilling brass and plastics.

NARRATION (VO):
The drill point, which does the work of metal cutting, is formed by two cutting lips and a chisel edge.

NARRATION (VO):
The cutting lips, when the drill is correctly ground, form two straight lines connected by the chisel edge. The length of the chisel edge depends on the angle it makes with the cutting lips and the thickness of the drill web or core.

NARRATION (VO):
The web thickness at the drill point is a compromise between thickness for rigidity and thinness for rapid penetration rates, larger flute space, and good chip clearance.
THE STANDARD DRILL POINT COMMONLY HAS A 118 DEGREE POINT ANGLE, SYMMETRICAL CUTTING LIPS, AND A CLEARANCE ANGLE TYPICALLY BETWEEN 10 AND 20 DEGREES.

--- TOUCH BLACK ---

NARRATION (VO):
FACE MILLING CUTTERS EFFECTIVELY GENERATE FLAT SURFACES WITH THE SPINDLE PERPENDICULAR TO THE WORK SURFACE. THE CUTTER BODY HAS MULTIPLE POCKETS TO ACCEPT A VARIETY OF INDEXABLE INSERT TYPES.

NARRATION (VO):

NARRATION (VO):
MOST MILLING WITH INDEXABLE-INSERT MILLING CUTTERS IS PERFORMED USING THE
highlighted

CT81D, CGS: Climb Milling Mode

‘CLIMB MILLING MODE’, WITH THE INSERT BITING INTO THE THICKEST PORTION OF THE CHIP FIRST AND THEN THINNING TOWARDS ZERO UPON EXIT.

NARRATION (VO):


NARRATION (VO):

THE MILLED SURFACE RESULTS FROM THE COMBINED ACTION OF CUTTING EDGES LOCATED ON THE PERIPHERY AND FACE OF THE CUTTER. THE FLAT MILLED SURFACE HAS NO RELATION TO THE CONTOUR OF THE INDIVIDUAL TEETH, EXCEPT WHEN MILLING A SHOULDER. NOT ALL FACE MILLS ARE USED FOR LARGE, STRAIGHT CUTS. SOME SMALL DIAMETER FACE MILLS ARE USED TO RAMP INTO A SURFACE, THEN PLUNGE TO A DEPTH, AND INTERPOLATE OUTWARDS TO MILL A LARGE POCKET MORE EFFICIENTLY THAN AN END MILL COULD.

--- TOUCH BLACK ---

NARRATION (VO):

SOME OF THE VARIABLES NEEDING CONSIDERATION IN THE DESIGN OF FACE
MILLING CUTTERS INCLUDE:

THE CUTTER’S EFFECTIVE DIAMETER,

CUTTER HAND,

CUTTER GEOMETRY,

INSERT POCKET DESIGN,

AND CUTTER PITCH.

NARRATION (VO):

FOR CUTTING, THE ‘EFFECTIVE DIAMETER’ IS

THE MOST SIGNIFICANT CONCERN. THE

EFFECTIVE DIAMETER IS MEASURED FROM THE

HIGHEST POINT ON AN INSERT ON ONE SIDE

TO THE HIGHEST POINT ON AN INSERT ON THE

OPPOSITE SIDE.

NARRATION (VO):

FOR PROPER POSITIONING, THE FACE MILLING

CUTTER’S EFFECTIVE DIAMETER SHOULD BE

ABOUT ONE-AND-A-HALF TIMES THE WIDTH OF

THE CUT DESIRED. THIS ALLOWS A QUARTER

TO ONE THIRD OF THE CUTTER TO OVERHANG

THE EDGES OF THE WORKPIECE, PROVIDING

OPTIMAL CHIP FORMATION.

NARRATION (VO):

THE CUTTER HAND IS DETERMINED BY

EXAMINING THE CUTTER’S FACE WHILE

RUNNING ON A MACHINE TOOL. A RIGHT-HAND

CUTTER ROTATES COUNTERCLOCKWISE...,

AND A LEFT-HAND CUTTER ROTATES
SCENE 40.
CT88A, CGS: Cutter Geometries
CT88B, tape FTD07, 06:06:47:00-06:07:10:00
inserts being tighten into milling cutter
CT88C, CGS: Radial Rake
Axial Rake

NARRATION (VO):
CUTTER GEOMETRIES OR ‘RAKE’ ANGLES ARE
DETERMINED BY THE CUTTER BODY AND THE
INSERT. TWO ‘RAKE’ ANGLES, THE ‘RADIAL’
RAKE, AND THE ‘AXIAL’ RAKE ARE
DETERMINED BY THE POSITION OF THE INSERT
POCKETS IN THE CUTTER BODY.

SCENE 41.
CT89A, CGS: Radial Rake
CT89B, ANI: positive radial rake milling
cutter
CT89C, ANI: positive radial rake milling
cutter with insert line
CT89D, ANI: positive radial rake milling
cutter with reference line
CT89E, CGS: Positive Radial Rake
CT89F, ANI: negative radial rake with lines
CT89G, CGS: Negative Radial Rake

NARRATION (VO):
The ‘RADIAL’ RAKE IS THE ANGLE MEASURED
BETWEEN THE INSERT FACE AND A RADIAL
LINE DRAWN FROM THE CUTTER AXIS TO THE
CUTTING EDGE, HENCE THE NAME RADIAL
RAKE. IF THE INSERT TILTS ‘TOWARD’ THE
CHIP GULLET, IT HAS A ‘POSITIVE’ RADIAL
RAKE..., IF THE INSERT TILTS ‘AWAY’ FROM THE CHIP
GULLET, IT HAS A ‘NEGATIVE’ RADIAL RAKE.

SCENE 42.
CT90A, CGS: Axial Rake
CT90B, ANI: positive axial rake milling
cutter
CT90C, ANI: positive axial rake milling
cutter with insert line
CT90D, ANI: positive axial rake milling
cutter with reference line
CT90E, CGS: Positive Axial Rake
CT90F, ANI: negative axial rake with lines
CT90G, CGS: Negative Axial Rake

NARRATION (VO):
The AXIAL RAKE IS THE ANGLE MEASURED
BETWEEN THE INSERT FACE AND AN AXIAL
LINE OR PLANE. IT MAY ALSO BE
POSITIVE..., OR NEGATIVE.

SCENE 43.
CT91A, tape FTD15, 15:33:10:00-15:33:25:00
zoom out, milling operation
CT91B, CGS: Negative Radial & Axial
CT91C, ANI: lines forming negative
radial/axial

NARRATION (VO):
The COMBINATION OF ‘AXIAL’ AND ‘RADIAL’
RAKE ANGLES YIELD THREE GEOMETRIES OF

NARRATION (VO):
THE ‘RAKE’ ANGLE ON FACE-MILLING CUTTER INSERTS IN CONJUNCTION WITH THE CUTTER BODY’S ‘RADIAL’ AND ‘AXIAL’ RAKE ANGLES CONTRIBUTES TO THE CUTTER’S ‘EFFECTIVE’ RAKE.

NARRATION (VO):

NARRATION (VO):
MOST FACE MILLS ARE DESIGNED WITH INSERT POCKETS THAT ARE FIXED. OTHER CUTTERS ARE MODULAR AND ACCEPT A VARIETY OF
INTERCHANGEABLE INSERT CARTRIDGES THAT HOLD VARIOUS INSERT DESIGNS AND SEAT THE INSERTS AT DIFFERENT ANGLES.

NARRATION (VO):

THE CUTTER PITCH IS DETERMINED BY THE NUMBER OF INSERTS RELATIVE TO THE CUTTER DIAMETER AND CAN BE DEFINED AS THE DISTANCE FROM A POINT ON ONE EDGE TO THE CORRESPONDING POINT ON THE NEXT EDGE. THE COARSER THE PITCH, THE LARGER THE CHIP GULLET.

NARRATION (VO):

MILLING INSERTS ARE AVAILABLE WITH VARIOUS GRADES AND SHAPES. IN ADDITION, MILLING INSERTS HAVE THEIR OWN CORNER GEOMETRIES, INCLUDING THE RADIUS..., AND THE WIPER FLAT.

--- FADE TO BLACK ---